HYDRIDIC EARTH
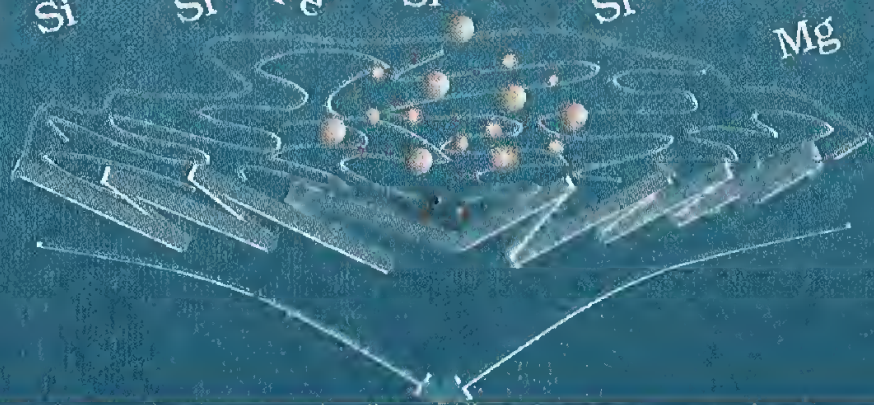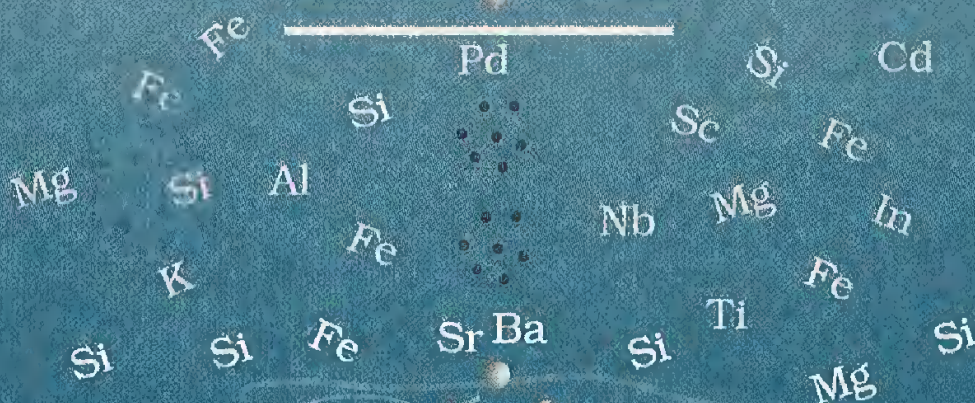
THE NEW GEOLOGY OF OUR PRIMORDIALLY HYDROGEN-RICH PLANET

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Edited on Translation

By: C. WARREN HUNT

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FOREWORD

It is my distinct privilege to have the opportunity to edit this landmark volume. I regard it as the most important treatise on Earth science fundamentals in the two hundred fifty years or so since Lomonosov, Lyell, and others first startled the world by discovering the rudiments of geology. Beginning with first principles and modern observations, V. N. Larin builds an edifice of entirely "new geology."

My interest and involvement arose from the observational side of the science. Independently I had settled on the concept of a primordially hydridic Earth, because internal hydrogen was essential [and the only possible chemical progenitor] for the violent endogeny that I had observed in the field. I first found strong support for my deduction in a brilliant paper by Rudolf Gottfried,[1] an east German geoscientist. His paper, which asserted the essential need for hydride systematics to explain the Earth's geospherical differentiation, appeared in a volume devoted to informed, skeptical treatment of plate tectonics theory. My perceptions utilizing the fundamental science set forth by Gottfried were then published in two books.[2] A contributing author to the second book, E.A. Skobelin of Krasnoyarsk, Siberia, sent me a copy of a 1980 book by another Russian, V.N. Larin, in which the idea of a primordially hydridic Earth was followed logically back to fundamental principles of the origin of the entire solar system. With the help of a Russian-speaking, Bulgarian geologist, Valentin Ivanov, I recognized that Larin broke new ground far beyond Gottfried's deductions or my own thinking.

This small volume expands on Larin's earlier book, presenting explanations based on hydride endogeny for the cosmochemical accretion of our planet, its early degassing, the initial formation of Archean granitic crust, Phanerozoic geosynclines, and Meso-Cenozoic oceans. Enigmas of element and isotope distribution are neatly resolved for the first time. Mascons on the Moon and past and present magnetism on the inner planets are explained. The benefits of intensive laboratory experimentation in the USSR and Russia since the earlier publication are made available to western scientists in this small volume. To accomplish this, the author's formerly scanty knowledge of English has blossomed, as he and I have toured geological sites in Canada and wrestled

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[1] Gottfried, R., 1990, "Origin and Evolution of the Earth: Chemical and Physical Verifications," in Barto-Kyriakidis, ed., "Critical Aspects of the Plate Tectonics Theory," v2, p115-140, Theophrastus Press, Athens

[2] Hunt, C.W., 1990 "ENVIRONMENT OF VIOLENCE: Readings of Cataclysm Cast in Stone;" Polar Publishing, Calgary

1992 "EXPANDING GEOSPHERES: Energy and Mass Transfers from Earth's Interior;" Polar Publishing, Calgary

over sentence after sentence to find the words to express nuances of profound scientific insight with fidelity.

Whereas I and co-authors Collins and Skobelin[3,4] had related endogeny to gaseous phenomena, Collins and I showed that the hydrides of silicon transform mafic rock to granite.[4,5] This enlarges continents and generates volcanism, hotspots, and earthquakes. Whereas Collins demonstrated a new concept of the origins of metal ores, Skobelin described a new theory on the origin of diamonds, and I proposed new concepts for the origin of coal, and hydrocarbons, all of our concepts were developed from field observations; and [perhaps predictably] all of us have been vigorously opposed and the value of our observational data discounted.

Larin performs the signal service of linking all of these phenomena within irrefutable principles of science as parameters of hydrogen effusion. He shows with eloquence that all are, inescapably, the corollaries of the unique behavior of hydrides, which must, therefore, result from core degassing of our primordially hydrogen-rich Earth. His concept is, indeed, new geology, a grand and unified theory of the Earth, new geology that is fully as revolutionary against the trenchant dogma of our day as Copernican astronomy was against that of two thousand years of the Ptolemies, Roman authority, and medieval Christianity. With this book, geoscience is freed from stale dogma and will never return.

Significant help is gratefully acknowledged by the editor for critique and review by Maurice Kamen-Kaye, Paul D. Lowman, Jr., and Lorence G. Collins.

C. Warren Hunt,
Calgary, Alberta, 1993

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[3] Hunt, C. Warren, 1990, ENVIRONMENT OF VIOLENCE: Readings of Cataclysm Cast in Stone, Polar Publishing, Calgary

[4] Hunt, C. Warren, ed. & author, L.G. Collins, author, E. A. Skobelin, author, 1992, EXPANDING GEOSPHERES, Energy and Mass Transfers from Earth's Interior, Polar Publishing, Calgary

[5] Collins, L.G., 1988, HYDROTHERMAL DIFFERENTIATION, Theophrastus Publications, Athens

CHAPTER I

"History shows us that science
progress permanently has been
retarded by the overbearing
influences favoring particular
concepts and impelling their
acceptance as dogma. Thus, it has
become necessary from time to time
to return to first principles,
which may be used without
constraint."

DeBroglie[1]

How much truth is there in the prevailing tenets of the Earth sciences?

Today there is no internally consistent theory for the origin of our planet. Instead, we have a collage of contradictory concepts, none of which adequately accounts for global geological history from the earliest periods. It is now evident that we are compelled to return to first principles to test the accommodation of present knowledge within their constraints.

In Earth science, a most fundamental premise is that the chemical composition of the planet is the basis for its internal processes. These processes themselves are believed to generate both the internal and the external features of the planet. Geologists considering global tectonics are restricted to the constraints of dynamic systems that are compatible with the most reliable model of internal Earth composition. If the "reliable" model is, in fact, incorrect, they will be led on circular paths of mistaken deduction by their incorrect precepts.

What, then, is known of the structure and chemical makeup of the interior of the Earth? How robust are present theories of Earth's internal structure?

At the beginning of the 20th century, geophysical science determined that our planet had a dense core, a huge mantle, and a relatively thin crust. In time it became clear that the concentric outer geospheres can be subdivided into additional subzones on the basis of density discontinuities and other physical properties. Table 1 shows present geophysical parameters, which are probably robust enough to withstand future change.

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[1] *Ed. note: French philosopher, scientist, and Nobel laureate in early 1900s.*

TABLE I

SPHERE	LAYER	DEPTH INTERVAL km	DENSITY g/cm^3	EARTH VOL. %	EARTH MASS %
CRUST	A	0 - 33	2.70 - 3.00	1.55	0.8
	B	33 - 400	3.32 - 3.65	16.67	10.4
MANTLE	C	400 - 1000	3.65 - 4.68	21.31	16.4
	D	1000 - 2900	4.68 - 5.69	44.28	41.0
	E	2900 - 5000	9.40 - 11.50	15.16	
CORE	F	5000 - 5100	11.50 - 12.00	0.28	31.5
	G	5100 - 6371	12.00 - 12.31	0.76	

Over the period in which these data have been collected, many assumptions have been made as to the chemical composition of the geospheres, and numerous geochemical models of the Earth have been created. Two of these are common today. Both recognize predominant silicate mineralogy in the crust and mantle. The fundamental difference between them is in the composition of the core.

In the earlier of the two models, an iron core is deduced. In the second, and later, model the core has the same silicate compounds as the mantle, but its oxidic [silicate] mineral is compacted and "metallized" by the high confining pressure.

In both models the core size is 16.2 % of Earth volume. That is less than one-sixth of total Earth volume. The remaining five-sixths of the volume is, therefore, the same in both models. There is no conflict between the models on this point – an implicit reason why they have peacefully co-existed for many decades of the 20th century!

More than 90 % of the volume of silicate minerals is taken up by their oxygen atoms. The space between the oxygens accommodates metal cations [silicon, magnesium, aluminum, iron, calcium, etc.]. Therefore, as both of the aforesaid models attribute an "oxidic composition" to the Earth, they intrinsically imply that oxygen is one of the most abundant of Earth's elements. All of this is fundamental dogma in geology today.

It is appropriate that we should inquire into the basis for this dogmatism. What facts support it? In part to answer our own question, it must be observed that the dense-core theory was assumed as a convenience, iron being the only heavy element known to be sufficiently abundant in nature to furnish the mass required. The molten Earth was, therefore, imagined as a kind of blast furnace – heavy metal below, light slag above. The idea was more seductive in the early part of the century, when blast furnace technology was a prevalent industrial technology.

The only bases for interpreting the Earth as a mainly oxidic and silicate body are its crustal composition and the supplemental data provided by meteorites. Let us consider the facts.

First, it is true that the crust as well as kimberlite magmas from deep levels of the mantle are of oxidic [silicate] composition. However, kimberlites originate at depths of 120-150 km, less than 2.5 % of Earth's radius. Kimberlite composition can hardly be taken as justification for the sweeping generalization that interior geospheres of the entire planet must be like the kimberlites, and have oxidic compositions. The concept stands in marked contrast to the easily demonstrated oxygen content of the outer layers of Earth, which diminishes with depth, as follows:

1. sedimentary rocks ————————————53%
2. granitic rocks————————————————50%
3. basaltic rocks————————————————44%
4. ultramafic rocks————————————————35%

Furthermore, the petrographic character of rocks of mantle origin, in particular inclusions of native iron and metal carbides, indicates that reducing conditions increase, and the incorporation of oxygen decreases with increasing depth (Maracushev & Perchuk 1973).

It is a widely-held opinion among Earth scientists that meteorites represent samples typical of the composition of Earth-type [stony or "chondritic"] planets. This assumption is the basis for the chondritic Earth model. Calculations made on a small sampling of meteorites, the orbits of which have been captured on photographic film or observed from multiple ground stations during descent, have implied a meteorite origin located in the asteroid belt (Bronshten 1976). Meteorite petrology clearly indicates origins at high temperatures and pressures (Kaula 1971), a fact implying probability of their origins as fragments from a large parent body or bodies, which disintegrated. It follows from this line of reasoning that there is no obvious alternative to the asteroid belt as the source for the meteorites that fall to Earth.

Thus it is that, whereas meteorites give some information on planetary composition, this information is related mostly to the asteroid belt, an area that I consider to be located excessively distant from the area in which the earth-type planets formed. The distance is on the order of three astronomical units, one unit being equivalent to the distance from the Earth to the Sun.

When a scientist takes meteorite composition as primitive Earth composition, he is assuming that asteroidal proto-planetary composition must have been identical to Earth composition despite the huge distance between them. In the next chapter it will be shown that this assumption is entirely unjustified.

However, there is yet another reason for refraining from seriously ascribing a common provenance to meteorite and Earth crustal compositions. This stems from the fact that the asteroid belt is intermediate in location between the small and the large planets, the stony- and gas-giant planets, that is to say. In this situation it is obvious that any differentiation that

resulted in the two radically different types of planets would have affected the composition and structure of the member in the asteroid belt as well.

Thus, it is my conclusion that there is no direct evidence to support the hypothesis of Earth's oxidic composition. It is quite impermissible to regard this idea as a singular and fundamental postulate in geology. Future historians of science will likely ask the question: *"Why in geology during the 20th century was the concept of an oxidic composition for the Earth taken for granted without any serious effort to prove it?"*

Farther on in this book the reader will find many objections to the Earth model entailing an iron core. Even the metallized silicate core is shown to be an unsatisfactory interpretation of the interior composition. Many researchers in many ways have proved both of these models to be substantially defective. Nevertheless, for some reason they let the consensus stand, apparently because no better alternative is available.

Our mission must, therefore, be to ask: *"Are the iron core and silicate mantle factual? And, if they are false, is there a way out of this blind alley?"* Manifestly, our inquiry must start at the beginning, that is to say, with the origin of the solar system.

Determination of the primordial composition of the Earth and other planets is a major goal in the sciences of cosmology and cosmochemistry. Unfortunately, existing theories in cosmology are inappropriate for determining the true composition of the Earth, because all of them seek to rationalize their answers to be consistent with the prevalent theory of the composition of the Earth. This circular reasoning leads inexorably back to a silicate/ oxide Earth.

Thus, increasingly we must distrust the traditional ideas of Earth composition. It is appropriate for us to reconsider the feasibility of processes that are thought fundamentals to the hypothetical origins of an oxidic Earth. To do this the serious researcher must, of necessity, draw on information from the existing well of cosmological theory. A plethora of radically differing theories fill the literature, a result of the lack of experimentation, which might provide the bases for constraints on the proliferation of cosmological hypotheses. Thus, the author has attempted to classify qualitatively the various theories using modern data.

For this purpose a comparison with respect to all chemical elements for which determinations are available are made between the Sun, the outer geospheres of the Earth, the Moon, and the composition of meteorites. This comparison reveals an interesting order of elemental distribution throughout the Solar system. Before specific discussion of this "cosmo-chemical order," it is desirable to list some assumptions fundamental in future schematics. These fundamental assumptions may be used without regard for the specifics of elemental behavior or, in particular, to the specifics at the levels of present knowledge.

I assume the present chemical composition of the Sun to be representative of its primordial chemical character, because the only changes the Sun is undergoing are those related to the synthesis of helium during thermonuclear

"burning" of hydrogen, and, to a lesser extent, synthesis of lithium and beryllium also. It is assumed that the chemical balance among heavier elements remains unaffected.

A second assumption is that the composition of the Sun's photosphere, which can be determined through spectral analyses, characterizes the whole of Sun chemistry. This hypothesis seems quite rational, because the Sun is a plasma body with a large exchange zone. This is the upper solarsphere, one-third of the Sun's radius and more than 70 % of its volume. Consequently, the composition of the photosphere represents the largest fraction of Sun volume.

A petrological peculiarity of meteorites is that their components were incubated in the womb of a quite large mother-body, a body of a size not less than that of the Moon. For an unknown reason the body disintegrated. From this assumption it is interpreted that the asteroid belt was the main source of the meteorites (Kaula 1971). The meteorites are thusly interpreted to represent the proto-planetary composition of the asteroidal belt, a zone that I have pointed out to be three astronomical units from the Sun, or three times farther from it than where the Earth formed.

Because meteorites are remains of a disintegrated body, they should represent all the different parts of it. Thus, an average meteorite composition should represent the entire range of the planetary matter of the asteroid belt. Calculation of average meteorite composition can best be done by looking at all the different types of meteorites that fall on the Earth. More than 70 out of 100 recovered meteorites are normally representative of ordinary chondritic composition. This statistic does not, however, take into account the carbonaceous chondrites, which are found among terrestrial collections in relatively small numbers.

These carbonaceous missiles have the distinctive characteristic of a weak structure, which can be mechanically disrupted quite easily. Hence, upon impact with the upper atmosphere, the carbonaceous chondrites are apt to disintegrate disproportionately more often than other meteorite types. Thus it is that the actual occurrence in space of carbonaceous chondrites is greater by a large multiple than the recovered number (Kaula 1971). When estimating average meteorite composition, it is necessary to take this fact into account.

The most popular appraisal of the Earth's composition today is based on the aforesaid a priori postulations, which are lacking in hard, factual [scientific] support. There is no guarantee that such postulations are correct. Therefore, attempting to avoid subjectiveness in making comparisons between interpretations of compositions of various zones of the solar system, I have used only known information on the compositions of the upper geospheres. And I disregard altogether speculative notions of the composition of the whole Earth.

Real compositions of the upper geospheres can be defined quite closely to be a mixture of mafic and ultramafic in the proportion of 1:3 (pyrolite, after Ringwood). Of course, this assumption is only justified insofar as these rocks of the outer geospheres exhibit a clearly recognizable signature of primordial planetary composition that shows itself in the abundances of the elements.

Figure 1

IONIZATION POTENTIALS vs ELEMENT DEFICIENCIES
THE CORRELATION IN EARTH'S OUTER GEOSPHERES

IONIZATION POTENTIAL - V
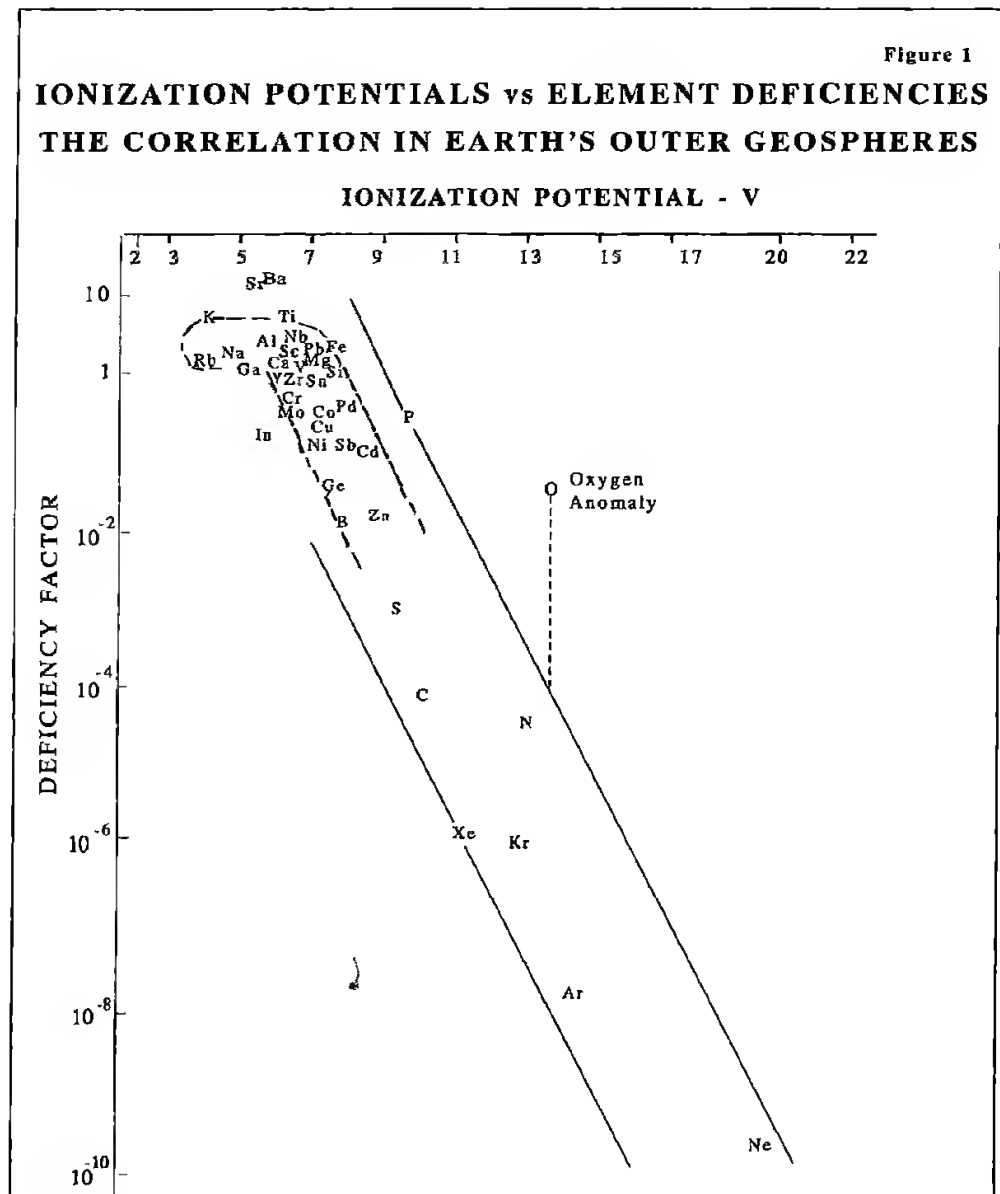
$$\text{Deficiency factor} = \frac{\text{Earth abundance of element}}{\text{Solar abundance of element}}$$

Element abundances are expressed as the number of atoms normal
to silicon. The number of silicon nuclei is taken as unity. For exam

$$\text{Solar Na concentration} = \frac{\text{Number of Na atoms on the Sun}}{\text{Number of Si atoms on the Su}}$$

*Solar composition is taken from Aller (1963), wherein the Earth's outer shell
is assumed to be one-quarter mafic and three quarters ultramafic (using clarkes
from Vinogradov). Deficiency factors for the inert gases are taken from V.I.
Moroz (1967). Lithium and beryllium are omitted, because they burn out in
solar thermonuclear synthesis. The dotted line is explained in the text.*

THE CORRELATION BETWEEN METEORITE COMPOSITION AND THE IONIZATION POTENTIALS OF THE ELEMENTS
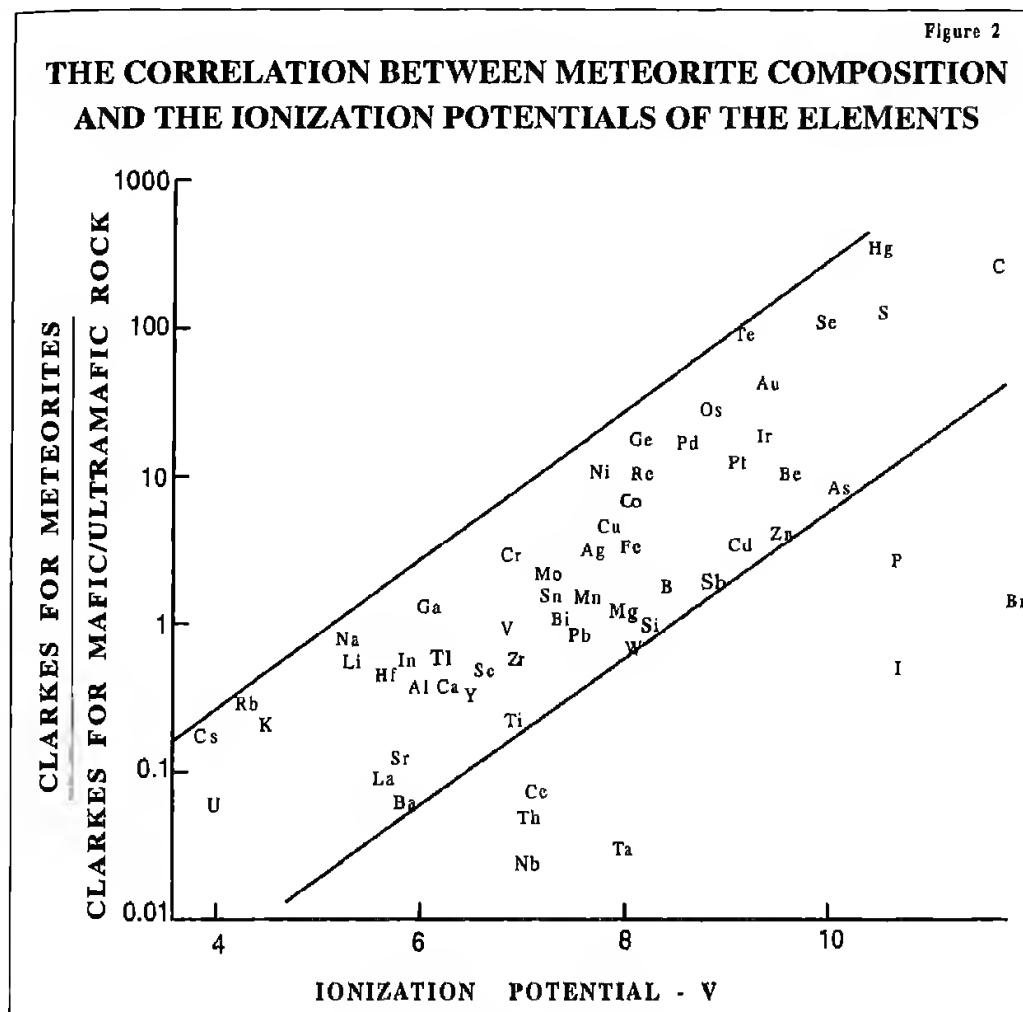
Figure 2 is a plot of the relative element abundances in meteorites against their ionization potentials. The elemental concentrations in meteorites are normalized to their concentrations in the mafic/ultramafic mixture (1 : 3) of terrestrial rocks. Data sources are shown in Table 2.

On first inspection this method may be seen to negate the usual notion that powerful forces for differentiation of the elemental components have operated inside the Earth to produce the granitic outer layer of the Planet. However, if one compares the concentrations of each element among the contrasting rock types, ultramafic - mafic - felsic, one discovers that only a small group of elemental concentrations vary by more than an order of magnitude, whereas the majority vary by less than one order of magnitude. Even the granites exhibit signatures of primordial planetary composition, signatures that can be revealed through analysis of the distribution of elements within them. The same holds true, but even more convincingly among mafic and ultramafic "mantle-type" lithologies.

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TABLE 2

ABUNDANCES OF THE ELEMENTS IN METEORITES AND TERRESTRIAL ROCKS

[G/TONNE UNLESS IN PERCENT]

ELE-MENT	METEOR-ITES	PYRO-LITE	ELE-MENT	METEOR-ITES	PYRO-LITE
Li	2.3	4.6	Y	1.4	5.6
Be	3.6	0.6	Zr	21	46
B	4.5	3.5	Nb	0.3	16.7
C	1.0 %	0.01%	Mo	1.1	0.75
Na	0.55%	0.77%	Pd	1.2	0.095
Mg	13.5 %	16.5 %	Ag	0.18	0.073
Al	1.25%	3.45%	Cd	1	0.4
Si	16.0 %	21.1 %	In	0.026	0.063
P	850	440	Sn	1	0.75
S	2.75%	0.03%	Sb	0.12	0.1
Cl	200	79	Te	0.8	0.01
K	0.06%	0.41%	I	0.2	0.5
Ca	1.37%	3.8%	Cs	0.073	0.4
Sc	6.7	19	Ba	4.3	83
Ti	0.055%	0.37%	Ce	0.67	12.4
V	67	93	Hf	0.38	0.95
Cr	0.28%	0.12%	Ta	0.019	1
Mn	0.18%	0.16%	W	0.23	0.47
Fe	23	9.2 %	Re	0.055	0.007
Co	700	125	Os	0.6	0.024
Ni	1.27%	0.153%	Ir	0.62	0.046
Cu	110	29	Pt	1.75	0.175
Zn	130	44	Au	0.17	0.0055
Ga	6	54	Hg	10	0.04
Ge	17	1.45	Tl	0.04	0.1
As	7	1.25	Pb	1.5	2.3
Se	11	0.13	Bi	0.04	0.05
Br	1.8	1.64	Th	0.042	1
Rb	2	7.7	U	0.014	0.25
Sr	11	117			

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Notes to Table 2: A. "Meteorite composition" is taken as the average between "normal" and "carbonaceous chondrite" compositions (Handbook ... 1971). Mafic and ultramafic abundances (for a pyrolite mixture of 1:3) follow the usage of Turekian &

Wedepohl (precise data [especially with respect to Bi, Te, Re, Se and Sb, the concentrations of which are raised by an order of magnitude in comparison to their clarkes in mafic and ultramafic rocks] from Handbook ... 1973); Ir and Os, according to a private communication from O. Ushko-Zakharova.

B.   There is a degree of uncertainty over the level of arsenic in meteorites. In his earlier work, G. Brown recognized in troilite and nickel-iron phases of meteorites that concentrations of arsenic reached levels of hundreds of grams per tonne. Brown's references include one where arsenic in stony meteorite is 2 g/t, a level appropriate only for a silicate phase of a chondrite and certainly inapplicable to the whole range of meteorites. My judgment favors arsenic minima of an overall average of 7 g/t with 5 g/t for troilites, 2 g/t for silicate phases.

Let us now continue by describing further the recognized cosmo-chemical order. Comparison of the compositions of the Earth's outer geospheres with the Sun's composition (Figure 1) reveals the existence of an order between elemental deficiencies and the ionization potentials of the elements. Deficiencies sharply increase when ionization potential increases. That is to say, elemental concentrations in the Earth relative to their abundances in the Sun sharply decrease in parallel with rising ionization potentials. It is to be noted that in this case, as well as elsewhere in the context of our analysis, we are considering only the ionization potential of the first orbital electron.

Comparison of meteorite compositions with those of the Earth's outer geospheres have demonstrated that the asteroid belt is enhanced in elements of greater ionization potential and deficient in elements of lesser ionization potential (Figure 2 and Table 2).

Although there have been tremendous advances in studies of the Moon, we still today have difficulty describing its entire composition. To describe definitively even the composition of the Moon's outer shell in a manner adequate to compare it with Earth's upper mantle is difficult. Because surficial planetary basalts are the most widespread of mantle derivatives, I made the   decision to compare their elemental concentrations. Obviously, they should have signatures representative of the primordial planet, or, at least, the composition of that volume of the planet from which the basalts originated.   It turns out that no significant correlation between element distributions and ionization potentials can be shown to exist within the systems of the Earth and Moon. The exercise of comparison failed to prove any regularity (see Figure 3 and Table 3).

Thus, comparisons among chemical compositions of the Earth-Moon system, the Sun, and the asteroid belt [as represented by meteorites], led to the discovery of a clear elemental order that is functionally related to the ionization potentials of the elements. This point needs specific emphasis. *Elemental distributions depend exclusively on the ionization potentials, not upon other physical characteristics* [such as atomic mass, atomic volume, melting temperature, volatilization temperature, and so forth]. This regularity

is evidence that, during the process of elemental differentiation, matter was in an ionized state, a plasma, in other words.

TABLE 3

COMPARATIVE ELEMENT ABUNDANCES
LUNAR BASALTS vs. TERRESTRIAL BASALTS
[In g/tonne unless in percent]

Element	Moon	Earth	Element	Moon	Earth
Li	11	17	Nb	12	19
Be	1.9	1	Mo	2.9	1.5
B	3.2	5	Pd	0.017	0.02
C	80	100	Ag	0.14	0.11
N	100	20	Cd	0.26	0.22
Na	0.24%	1.8%	In	0.85	0.22
Mg	6.6%	4.6%	Sn	1.6	1.5
Al	6.15%	7.8%	Sb	0.46	0.2
Si	20.42%	23 %	Te	0.047	0.01
P	325	1100	I	0.14	0.5
S	600	300	Cs	0.2	0.11
Cl	28	60	Ba	190	330
K	0.15%	0.83%	La	10.2	15
Ca	7.2 %	7.6%	Ce	30.4	48
Sc	43	30	Sm	9.87	5.3
Ti	1.9 %	1.38%	Eu	1.66	0.8
V	88	250	Gd	8.5	5.3
Cr	2380	170	Yb	5.25	2.1
Mn	2000	1500	Hf	5.8	2
Fe	14.7%	8.65%	Ta	1.13	1.1
Co	43	48	W	0.3	0.7
Ni	133	130	Re	0.0021	0.00071
Cu	23.3	87	Os	0.015	0.01
Zn	19.4	105	Ir	0.0085	0.02
Ga	4.5	17	Pt	0.05	0.1
Ge	0.95	1.3	Au	0.002	0.004
As	0.8	2	Hg	0.074	0.09
Se	0.30	0.13	Tl	0.0016 ? *	0.21
Rb	3.92	30	Pb	2.42	6
Sr	178	465	Bi	0.0032	0.007
Y	81	21	Th	2.79	4
Zr	265	140	U	0.8	1

* *The dispersion of Tl on the Moon surface is extremely high, with specimens enriched up to four orders of magnitude.*

Note to Table 3: Samples of lunar undifferentiated basalts were sampled on the Apollo 12 and Luna 16 missions (Terrestrial basalts - after Turekian and Wedepohl, new data from Handbook ... 1973).

A plasma state was possible only during the earliest primordial period of the solar system. Thus, the coordination of element distribution with ionization potential seems quite natural, because it is known that most of the present mass of the universe is in the plasma state. However, element separation within a plasma is brought about by, and only possible in, a magnetic field.

THE RATIO OF ELEMENTAL ABUNDANCES IN LUNAR MARE BASALTS TO THOSE IN TERRESTRIAL BASALTS PLOTTED AGAINST IONIZATION POTENTIALS
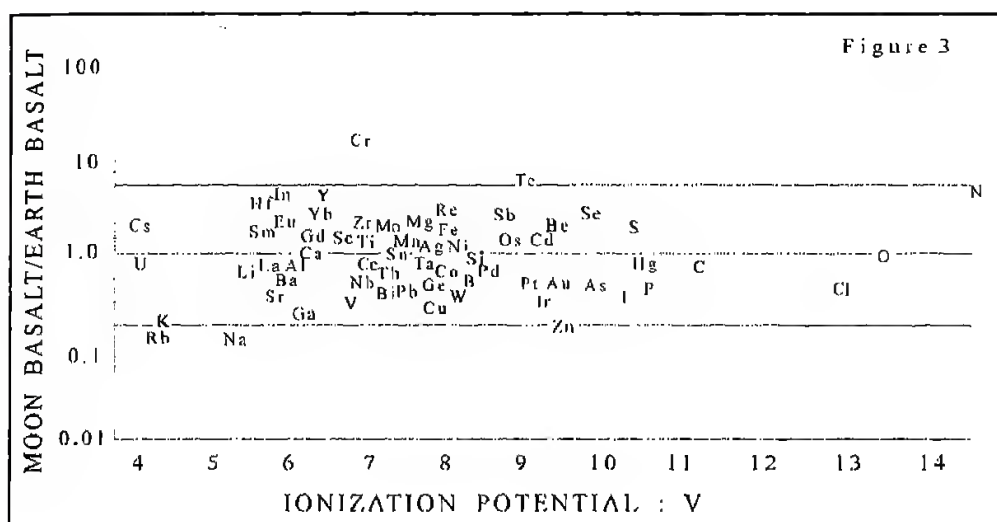
Figure 3

If we use the cosmo-chemical order (Figures 1, 2, 3) as a criterion for the evaluation of the different concepts of cosmology, we can eliminate most proposed theories. For example, on this basis we will not have to consider any cosmological concepts which do not represent primordial matter as a plasma within a magnetic field. In addition, we must disallow all theories that presume the prior existence of a proto-Sun to which cloud-like dust and gas from surrounding space was attracted, captured, and then compressed from a dispersed cloud mass into a protoplanetary disk.

The controversy here is over whether the process of differentiation should be considered one of movement of protoplanetary mass from the periphery of the cloud toward the center. The mode of element concentrations that I have described implies that the movement of matter during organization of the protoplanetary disk should be exactly the opposite — from the center toward the periphery. This proposition is addressed further in coming pages.

From among the many divergent theories of cosmology, only one partially conforms to the regularity I have recognized. Before naming it, let us discuss briefly the generalities that must be satisfied in the creation of a planet.

Scientific cosmology during the last two centuries has accumulated enough facts to have invalidated most theories such as (1) the accretion of protoplanetary matter around the Sun, and (2) the ejection of protoplanetary matter from the Sun by a cataclysmic event of some sort. The facts that confound these theories include the coincidence of the solar equator and the flatness of the ecliptic, the right-hand rotation of the planets, the small eccentricities of planetary orbits, the orientations and distribution of planetary momentum in the solar system, and other facts of cosmological science.

The nebular concept, which comprises the idea of simultaneity in origin for the Sun and planets from a single nebular cloud, is supported by modern cosmological facts. It maintains that the creation of the solar system commenced with a nebular cloud of dust and gas, that made up the intra-stellar medium of our galaxy. Approximately 4.57 billion years ago, a supernova exploded in the neighborhood of this nebula. As a result of this event, the nebula lost its gravitational stability and commenced to collapse. From its initial angular momentum, the nebular collapse moved to faster and faster rotation as collapse progressed. At the instant when centrifugal force equalled gravitational attraction, matter at equatorial latitudes started to flow outward. From this beginning the protoplanetary disk, oriented in the plane of the ecliptic, proceeded to form.

It can be shown by calculation that the moment of rotational instability of the proto-Sun was reached when its radius equalled to the radius of the orbit of Mercury. Evolution from that point of instability turned the proto-Sun into our star, its protoplanetary disk emerging with the full complement of planets.

The theory of simultaneous origins for the planets and the Sun has prevailed generally for the last two centuries (Kant & Laplace), notwithstanding that it fails to explain why 98 % of the momentum (mvr) of the system is concentrated in planets which have aggregate mass of less than 1/700 the mass of the Sun. It is perfectly clear that during solar system formation there was a mechanism that brought about the transfer of momentum from the central regions of the system to its peripheries. Until recently this enigma was not recognized. It is impossible to describe nebular development without taking into account the enigmatic distribution of momentum in the solar system. Obviously, ongoing collapse of the nebula, after it passed the point of rotational instability, must have been arrested at some point by the increasing rotational velocity. In this connection we should underline the fact that it is this distribution of momentum within the solar system which has been the point on which all hypotheses [prior to that described next] have failed.

A resolution of the enigma was developed by Fred Hoyle in 1958. He suggested that, during formation of the protoplanetary disk, a dipole magnetic field existed in which the magnetic flux lines were linked rigidly with partially ionized nebular matter, like "spokes of a wheel." In this way the system could conserve rotational velocity at different distances from the axis of rotation. This model provides the appropriate mechanism for the transfer

of momentum from the central regions of the collapsing nebula to peripheral regions.[2] As momentum is transferred outward, the central dense regions experience reduced rotational velocity (in the manner of a figure skater reaching outward). Simultaneously the central regions experience reduced rotational instability, which lead to their continued collapse. Also simultaneously, the peripheral regions of the nebula, on account of their high momentum, move on the planar ecliptic still farther outward from the central nebular region to form the protoplanetary disk (Hoyle 1960).

It is my opinion that this aspect of the Hoyle concept can be used to explain the origin of the previously-recognized cosmochemical order. During protoplanetary disk formation, primordial matter, which had been "leaking" from the proto-Sun and spreading outward in the Sun's equatorial plane, moved perpendicular to the lines of magnetic flux. Ionized particles, having only inherent thermal velocities, were unable to move through the flux and were diverted and isolated by the magnetic dipole field and compelled to remain within the inner regions of the protoplanetary disk. At the same time, neutral particles were propelled outward, fractionated magnetically, that is to say, into peripheral regions of the disk. This situation is represented in Figure 4.

Figure 4
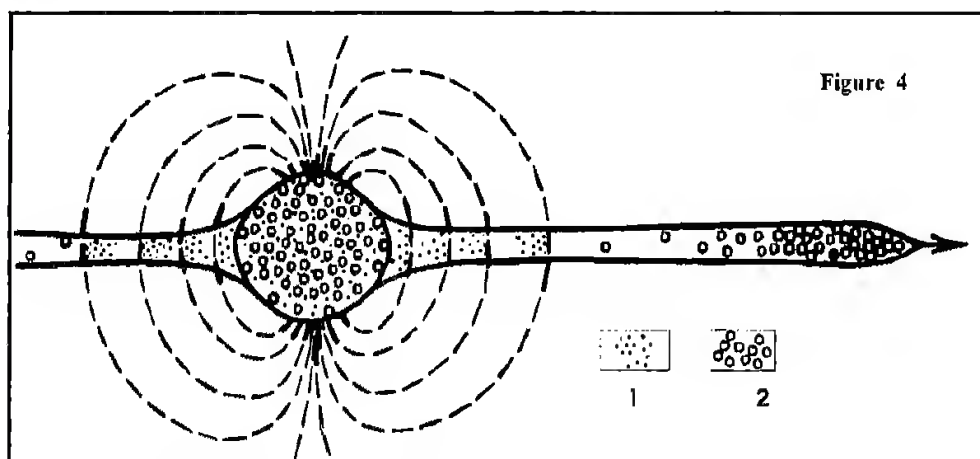
MAGNETIC DIFFERENTIATION

Magnetic differentiation of particles in the protoplanetary disk by the magnetic field of the proto-Sun.

1   ionized particles;   2   neutral particles

Particle conditions [whether ionized or neutral] depended on ionization potential. If the ionization potential had been lower, there would have been more probability for an ionized particle to be captured by the magnetic field.

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[2]   *The equation of momentum, MVR can be written as MWR^2, where W = angular velocity. When angular velocity is constant at various distances from the center of the system, momentum tends to be concentrated in distal regions of the nebula as a function of R^2.*

Higher ionization potentials define higher likelihoods for neutrality. The different potentials, thus, make fractionation possible.

Thus, it is seen that magnetic segregation among ionized particles worked in coordination with their ionization potentials and provided the most likely scenario for the primordial process that took place. It affords a natural explanation for the cosmochemical order that I have defined (Figures 1,2,3). Relatively larger elemental deficiencies on Earth with respect to solar abundances are parallelled by increased ionization potentials. This linkage is explained as a consequence of reduced ionization, and hence, less chance for particles to be captured by the magnetic field.

Furthermore, it becomes readily understandable why meteorites are so much richer in gold, platinum metals, and mercury and so deficient in uranium, potassium, and rubidium relative to Earth. The first group of metals has higher ionizion potentials; the latter group has lower ionization potentials.

The asteroid belt, which is located three times as far from the Sun as the zone in which the Earth was formed, following magnetic differentiation, should have been enhanced in elements with higher ionization potentials and diminished in elements with lower ionization potentials through the effects of differentiation and retention in the magnetic field of the Sun.[2] On the other hand, by comparison, in the formation of the Earth and Moon at the same distance from the Sun, the elements occur in identical chemical compositions.

The possibility for differentiation of ionized protoplanetary matter by the magnetic field has been suggested in earlier studies. Astrophysicist V.I. Moroz speculated that this process explains the differences between the inner and outer planets. The inner ("Earth-type") planets are enriched in easily-ionized metals, which could have been retained by the magnetic field of the proto-Sun; the outer (gas-giant planets), as their name implies, are made up mainly of gases, which have generally higher ionization potentials (Moroz 1967).

Deficiencies of inert gases in the Earth are also amenable to being explained as fractionation effects on these elements in the inner regions of the protoplanetary disk. The dependancy of these processes on elemental ionization potentials have been described by Iokipii (1964). In this light my cosmochemical insights (Figures 1, 2, 3), the Moroz speculation, and the Hoyle hypothesis of the distribution of momentum by protostellar magnetic fields, all conform essentially to the observable facts. That being true, we are afforded an important perspective from which the composition of the primordial Earth and some of the chemical peculiarities of the other inner planets can be established as a

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3   If, during protoplanetary disk formation, material moved inward from the periphery toward the center of the nebular cloud, as some investigators have concluded, the distribution of elements between the Earth and the Asteroid belt must result in a distribution exactly opposite to the picture shown in Figure 2. Meteorites should then be enriched in uranium and potassium, and the Earth should contain much more mercury and gold.

generalization resulting from magnetic differentiation.

However, before particular problems of primordial Earth composition can be addressed, we must find the answer to the question, *"Why does oxygen not follow the general order of the other elements?"* (Figure 1) Oxygen concentration in Earth's outer geospheres is several times higher than the expected theoretical value as interpreted from magnetic differentiation. There are two possible explanations for this anomaly. **(1)** *Oxygen, unexpectedly, for an unknown reason, was differentiated by the magnetic field in the same manner as a metal, although by comparison with metals, oxygen has a significantly higher ionization potential.* **(2)** *The initial concentration of oxygen in the Earth was relatively small; and, during planetary development, oxygen has become redistributed to the outer geospheres, where it is now concentrated.*

CHAPTER II

Comparative Cosmochemistry and the Original Composition of the Earth

Let us consider the first scenario expressed at the end of the Chapter I. If the oxygen ionization potential were decreased to 7-8 V, the element could be captured by a magnetic field in the manner of a metal. However, decrease of ionization potential is only possible when oxygen is bound into compounds which themselves are more easily ionized. The question then becomes: "Was there any possibility for chemical bonding during the episode of magnetic differentiation?" It is very important to emphasize that the cosmochemical order that we uncovered provides evidence for the existence of a highly ionized plasma of proto-matter during differentiation. Without this plasma, magnetic differentiation is, quite simply, impossible.

The order of elemental distribution (see Figure 1) shows that elements having ionization potentials close to 7-8 V have deficiency coefficients equal to one. This is only possible if a magnetic field had captured their nuclei relatively efficiently according to their ionization potentials. These metals must have been highly ionized; and the protoplanetary cloud, during magnetic differentiation, must have existed with levels of energy sufficient for the elements with ionization potentials of 7-8 V to have become ionized.

This energy is equal approximately to 675-770 kj/mol. Estimation of the thermodynamic condition of the system shows clearly a heterogeneous interactivity, inasmuch as chemical bonding is precluded during magnetic differentiation. The concentration of energy that led to ionization was much more intense than the chemical bond energies between oxygen and other elements. Hence, all chemical compounds must have been fully dissociated as ions and atoms, the normal condition for a plasma.[1]

Hence, we may conclude that if, during the time of magnetic differentiation, there is no opportunity for chemical reaction, and we cannot

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[1] *Simultaneously, a plasma, despite a higher degree of ionization, could be "cold" because of non-isothermistry. It could have a relatively low temperature in the nucleus along with relatively high electron temperature. This is probable if ionization occurred the "hard way," by penetrative means such as x-ray or g-ray irradiation under conditions in which the plasma remains "transparent" to the relatively "soft" radiation of thermal photons.*

accept that any oxygen compounds could exist under these conditions, then it would appear that the oxygen ionization potential must have been maintained at its usual value of 13.6 V. In that mode oxygen could not be retained by the proto-solar magnetic field together with metals having ionization potentials of 7-8 V. Oxygen should have been ejected by fractionation together with other less-easily-ionized gases from the zone of formation of Earth and the other stony planets to the zone of giant-planet formation.

Thus, it becomes apparent that, because the first explanation broached at the end of Chapter I is not acceptable, we may accept the second, which implies that primordial oxygen on Earth was quantitatively less than has been generally recognized. In this scenario, it must be considered still probable that during planetary history, oxygen repositioned itself and enriched the outer geospheres. Given these conditions, is there really any such thing as an "oxygen anomaly?" (see Figure 1)

This conundrum brings us to formulate the main thesis that is advanced in this chapter. On the basis of the magnetic differentiation theory, our knowledge of solar abundances, and by implementation of the formula $C_e = F \cdot C_s$ [where C_e = any unknown element concentration in the Earth, C_s = any known element concentration in the Sun, and F = a deficiency coefficient] we can make a rough approximation of the composition of the primordial Earth.

In this formula, the assumption is that F is an "original" value of deficiency, that is to say, the value actually originating with magnetic differentiation. It is necessary not to confuse this with the "observed" value. The latter is obtained by comparing the content of the outer geospheres with solar abundances. Most elements have quite similar "primordial" and "observed" deficiency coefficients. This near equality shows that the outer geospheres contain clear signatures of the primordial planetary composition. Failing this, there would be no way to develop a cosmochemical order, such as shown on Figure 1.

In contrast with the aforesaid normal order, some elements occur in the outer geospheres in abundances that are dramatically different from primordial values. Where an observed deficiency coefficient for an element does not conform to the general trend (the cosmochemical order) it may be interpreted that the element has been redistributed within the planetary body. From the cosmochemical order [which is the result of magnetic differentiation] it is possible to derive the primordial, deficiency coefficient that prevailed after the redistribution of elements into the general order based ionization potentials.

Metals in general have ionization potentials of less than or equal to eight volts (≤ 8 V) as displayed graphically in Figure 1. This shows that metal coefficients are similar to one another and also close to unity. Obviously, this similarity results from equally effective ionization, a behavior which is only possible if ionization is substantial and magnetic differentiation is complete. If the level of radiation had been sufficient to ionize silicon [which has an ionization potential of 8.15 V], all elements with lower

potentials [the metals] must already have been ionized completely. Therefore, the Earth should have inherited the solar spectrum of elements with ionization potentials of < 8 V, the metals, that is to say. It follows, furthermore, that the relative abundances of metals on Earth must correspond to their relative abundances in the Sun.

The conclusion that follows from the foregoing is that, among terrestrial metals, silicon and magnesium, and to a lesser extent, iron, should reflect a distribution representative of the Sun. That is to say, these elements must dominate others on Earth. Aluminum, calcium, and sodium should have less significant roles; and the remaining metals represent but small to vanishing percentages of total Earth mass.

Sulphur, carbon, and nitrogen are all widespread on the Sun, where they occur in order next only to hydrogen and helium. However, their elevated ionization potentials along with correspondingly higher deficiency coefficients imply relative concentrations on Earth that are less than anticipated values by two to three orders of magnitude (Table 4).

We have already seen that the magnetic separation of oxygen is unlikely because of its ionization potential; and I have described why two scenarios that have been invoked to explain its occurrence would have been impossible. Oxygen should, in fact, be located within the zone of ambience defined by its primordial deficiency. On this basis, oxygen in the planetary body should be three orders of magnitude less than in the Sun.

The theoretical planetary balance of original element concentrations based on magnetic separation is shown in Table 4. Although the data are approximate, they nevertheless impose severe constraints that effectively contradict many commonly accepted beliefs in the Earth sciences. One of these is that most of the mass of our planet is "oxidic" in composition, that is to say, made up primarily of oxides and silicates. This compositional predominance is manifestly impossible under the constraint of magnetic differentiation, which must inevitably have restricted oxygen concentration within the planet to one or, at most, a few percent.

It must be remembered that the proto-matter, which "flowed" from the proto-Sun, was dominantly hydrogen. If the hydrogen deficiency coefficient (relative to an ionization potential of 13.6 V) is taken as 10^{-3} - 10^{-4}, the initial hydrogen concentration in the orbital zone of the Earth must have been high enough to allow all elements to exist as hydridic compounds with a stoichiometric form of EH - EH_2 (see Table 4). There is, thus, no problem for the retention of hydrogen throughout the process of proto-matter condensation, because metals, as explained below, have a strong affinity for hydrogen. There is, for example, a report on the condensation of iron vapor in an atmosphere of hydrogen in which each metallic atom "attracted" a matching hydrogen molecule (Galaktionova 1967).

Hence, there is a significant likelihood that the primordial composition of Earth was permeated with hydrides. At the same time, the percentages by weight of hydrogen in the whole planetary mass would have been a mere few percent. It has to be emphasized that this conclusion is based, not on some

abstract speculation but, after the discovery of the cosmochemical order and after analyses making use of all available information on the composition of the solar system.[2]

			Distribution on the Earth		
Element	Solar abundance (normalized to silicon)	Deficiency factor [primordial]	normalization to silicon	volume percent	weight percent
Silicon	100	1	100	19.5	45
Magnesium	79	1	79	15.5	31
Iron	13	1	13	2.5	12
Calcium	4.5	1	4.5	0.9	3
Aluminum	5	1	5	1.0	2
Sodium	3.6	1	3.6	0.7	1.5
Oxygen	3,000	10^{-3}	3.0	0.6	1.0
Carbonm	1,600	10^{-3} -10^{-4}	0.16 - 1.6	0.03 - 0.3	0.03 - 0.3
Sulphur	60	10^{-2} -10^{-3}	0.06 - 0.6	0.01 - 0.1	0.03 - 0.3
Nitrogen	300	10^{-4} -10^{-5}	0.003 - 0.03	< 0.01	< 0.01
Hydrogen	3,000,000	10^{-3} -10^{-4}	300	59	4.5

TABLE 4

THE CHEMICAL COMPOSITION OF THE PRIMORDIAL EARTH
[with reference to the process of magnetic differentiation]

Notes: 1. Solar abundances are taken from Aller (1963).

2. The frequent association of iron with manganese chromium, and cobalt is taken into account in selecting iron abundance figures.

The linkage we have established between magnetic differentiation and comparative cosmochemistry will be central to all the author's further speculations. It can be verified experimentally in some cases and affords clear and specific predictions relative to some chemical peculiarities of the inner planets without altering the model. The aforesaid chemical behavioral pattern can be readily verified with today's technological capabilities.[3]

We will now discuss an objection, which has repeatedly been brought up with the author during the initial consideration of this book. It originates with the view that is commonly envisioned today for the disk of protoplanetary matter that is conceived as partitioned from the proto-Sun. The condensation process is imagined to have started immediately as temperatures fell. This

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[2] *Further study of solar composition using the power of modern astrophysical science is extremely important, especially in extending the list of elements analyzed on the Sun to include the trace elements such as gold, mercury, the halide group, and others having ionization potentials above 9V.*

[3] *This subject is taken up again in Chapters IX, XI, and XII.*

process, which is thought to have proceeded for less than a year, yielded aggregated particles up to 2 cm diameter. Partitioning and aggregation are thought to have rendered the particles inert to magnetic field forces. This prevailing line of thought is that the process of planetary accretion was one of gradual aggregation and compaction of particles up to the stage of individual bodies independently accreted to Asteroid- or even Moon-size.

The concept of rapid aggregation within the disk is in conflict with the differentiation of protoplanetary matter by magnetic force and with Hoyle's idea of magnetic redistribution of momentum. It is apparent that in a scenario of fast condensation there is little opportunity for magnetic differentiation. Some researchers have looked at this point as a major obstacle to the primordial hydridic Earth hypothesis.

We need not accept this argument, but we should be aware just how specious it is. The notion of rapid condensation is not a fact, but a speculative suggestion of a process that is taken to be probable merely because it seems reasonable. The cosmochemical order, on the other hand, which I have discovered, is empirical fact, evidence that may not be ignored. Any cosmological theory must accommodate it.

In this context the ideas supportive of rapid condensation of matter in the protoplanetary cloud are inappropriate, because they fail to explain the elegant cosmochemical order of the solar system or the Hoyle concept that supports it.

Of course, the question remains: "Why should there have been a delay in condensation from the protoplanetary cloud?" In fact, the delay was a natural consequence of the original supernova explosion that triggered the creation of the solar system and provided initial impulsion and simultaneous nucleo-synthesis in this entire region of the universe (Hoyle & Fowler 1964). This, of course, was the event by which the dust-gas nebula became enriched in heavy elements [uranium, thorium, and other elements near the end of Mendeleev's periodic table].

Simultaneously with synthesis of heavy elements, many light, short-lived isotopes were also created (Sobotovich 1971). Consequently, a high level of radioactivity prevailed in the nebula during early stages of solar system development. From a different perspective, radioactivity, accompanied by ionization (loss of outer electrons) of gas produced particles of equal positive potentials and interactive repulsion. The entire scenario arose from magnetic differentiation within the evolving disk. Rapid condensation was, for this reason, delayed by "Coulomb forces." It is most likely that condensation started only after the decay of short-lived isotopes.

1. The time required for collapse of the proto-nebula was the time between loss of gravitational stability and the formation of the protoplanetary disk. This is estimated as 10^6 years (Reeves 1976). Short-lived isotopes produced in this process are most likely to be ^{10}Be, ^{26}Al, ^{53}Mn, ^{60}Fe, and others with half-lives that approximate 10^6 years.

2. It is important to realize that the perception of rapid condensation

of matter in the protoplanetary disk by agglomeration of solid particles was never formulated through a process of logic; and computer modelling of the process shows that it is difficult to deliver a discrete, small number of planets by agglomeration. More readily one finds that small planets result from the model and that they occur in much greater numbers. Furthermore, models always arrive at an irreconcilable situation wherein solid bodies grow to a certain size relatively quickly, after which the speed of their agglomeration abruptly decreases along with the number of bodies that grow to larger sizes. It then becomes possible through gravitational interaction for the accreting planetesimals to be boosted to high velocities in elliptical orbits: orbits, that is to say, with greater eccentricities. Such eccentricities intrinsically raise relative velocities and, therefore, the likelihood for collisions and disintegration instead of consolidation.

Research has been conducted to try to resolve this dilemma by assuming an initial growth of "embryo" planets with masses exceeding the other particles of the nebular swarm by two orders of magnitude. In this model it is demonstrable that the remaining matter would fail to be accreted by the "embryos." However, there is no known evidence of any mechanism that would create the "embryos" in the first place. In mathematical modelling they are not produced spontaneously. Neither is there any way for the embryonic planetesimals to evolve into the specific orbital positions of future planets. It is, therefore, unjustified to explain the entire sequence by which planets evolved as no more than the outcome of a game of probability. If we believe this, we are living in an incomprehensible world.

During the late nineteen seventies, at the Institute of Applied Mathematics of the USSR Academy Science, a radically new model for the process of creation and accretion of the solar system was conceived and developed. The authors of this model, T.M. Eneev and N.N. Kozlov (1981), showed that all major behavioral characteristics of the solar system can be precisely simulated by computerized numerical modelling, if, during accretion, the protoplanetary disk is characterized by scattered particles comprising agglomerated globules. These are droplets with densities several orders of magnitude less than any possible solid particles. Realistically, these globules should be thought of as aggregations of gas molecules.

Furthermore, during the initial stages of the accretion process, these agglomerations must necessarily have been compressed into a disk. Their gravitational attraction must have behaved according to the law governing absolutely non-rigid collisions. That is to say, interrelationships converged into gravitational adhesion. At first this conversion would have created bridging with tidal oscillation. Finally, the oscillating masses would have merged into permanently coherent bodies.

The authors of this scenario confessed their initial reluctance to oppose the prevailing doctrine of planetary accretion involving solid particles. They only anticipated simplifying the current theory by means of computer techniques. However, they passed a point of no return when they considered the physics

of agglomeration of "liquid globules" [possibly 700-1000 km diameter].

Every meeting of two globules may be considered a merging, a gravitational pairing in which the two globules continue to rotate around their combined center of gravity. which itself assumes the orbit of their combined angular velocities. Thus, it is possible to represent them as a single globule with a mass concentrated at the center of gravity. This simplification makes it possible to apply computer techniques to tens of thousands of globules, where previously the best computer programs working on solid particles could deal with no more than a thousand.

Remaining, however, was the unresolved problem of how a disk could evolve with 25,600 globules that circulate in the gravitational field of a central body, while maintaining nearly circular orbits ("Kepler's orbits") and while still interacting gravitationally with each other? The computer surprised everyone with astonishing results. The model generated a master plan that simulated our solar system! Its features included the number of planets, their minimum separation distances according to the Titus-Bode law, their orbital particularities [including both normal rotation in the direction of orbital motion and retrograde rotation, opposite to orbital motion, as typified by Venus!].

Elegant consistency between the model and reality was demonstrated by this exercise. It is especially significant that the model demonstrated not only the mechanism for capture of the totality of protoplanetary matter but for the formation of protoplanets as well. The mechanism is elegant in that there is no residue nor any superfluous volatile protoplanetary matter to take into account. In addition, the Eneev-Kozlov model interprets proto-Earth formation over a period of some 10^4 -10^5 years as a large, diffuse sphere of one-million km radius. Other protoplanetary accumulations must have had similar forms. Otherwise it is impossible to explain the origins of the inclined axes of planetary rotation.[4]

It is only after the aforesaid diffuse-sphere stage that the protoplanets, including the proto-Earth, became solid bodies through the compressive effects of gravity. Therefore, the implication that, during planetary accumulation, the first step was accretion of their entire masses into globules or "dust-gas" globules,[5] followed by a second stage of gravitational accumulation, appears entirely logical. This scenario, which follows directly from the Eneev-Kozlov model, is materially supported by the cosmo-chemical order (see Figure 1). Comparison of the elemental compositions of the Earth and Sun

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[6] *On this topic T.M. Eneev and N.N. Kozlov use the theory, which was developed by V.V. Beletskii, for satellite movement relative to mass centers in the gravitational field.*

[7] *The internal plasma state of the agglomerating proto-planet precluded the existence of true "dust-gas" (a condensation product) in its makeup. That is why the traditional term is placed in quotation marks.*

has allowed us to reach the conclusion that in the process of creation of our planet there was no general loss of elemental matter. All elements are to be found in a distributive pattern consistent with their original magnetic differentiation.

Thus, it is proper to interpret that, during the accumulation of dispersed protoplanetary disk-matter into a solid planetary body, no element diminishes in abundance. If that were the case, loss of some elements below their known cumulative concentrations would create deviations from recorded fact (see Figure 1).

Existing theory, which involves the presumption of initial condensation followed by accretion, proves unconvincing as to its efficacy for preserving without loss all matter that is ejected during magnetic separation. In such a case there would obviously be ample opportunity for any volatile phase (for example, the inert gases) to be dispersed and lost from the system.

The new accumulation model, on the other hand, accommodates this constraint very well. It requires a plasma state for protoplanetary matter. In a plasma the Coulomb barrier prevents condensation, and the pressure conditions of gas dynamics in plasma oppose gravitational forces, thus preventing gravitational collapse of the proto-matter. Disk plasma conditions allow (and even require) consideration of the possibility that magnetic forces participated in the evolution of the protoplanetary disk. According to Fred Hoyle (1960), during the process of transferrence of momentum, the lines of magnetic flux extended in a helical manner out into the proto-planetary disc around the proto-Sun. The helix created instability of the proto-planetary matter and divided it into discrete rings in which flowed electrical current induced by fluctuations of the magnetic field of the proto-Sun. Fluctuations of the magnetic field caused pinching effects in the rings of proto-planetary matter, so as to make the rings resemble strings of beads. .

Thus, cosmochemical order is evidence for the plasma state of proto-matter in the nebular stage of solar system formation. The pinch effect, acting on the plasma at a certain point, precisely allowed generation of globules in the protoplanetary disk. The research carried out by T.M. Eneev and N.N. Kozlov, as mentioned, shows that gravitational evolution of such a model can only produce a planetary system with all the known characteristics (planet numbers, orbits, and rotational characteristics) if planetary accretion precedes condensation.

In this scenario, immediately after accretion, the Earth-type planets comprised scattered gaseous spherules. With diminished levels of radiation (due to the decay of short-lived isotopes) and decrease of the Coulomb barrier, the process of condensation, agglomeration, and collapse commenced. Within a gravitationally-controlled spherule of protoplanetary matter the growth of larger bodies was impossible. The condensation process of planetary matter followed by its collapse into solid bodies is best thought of as a "snow fall" directed toward the mass center of the proto-planet, rather than the popular concept of our day, an energetic bombardment of embryonic

planets by asteroid-sized, solid bodies.

In future chapters I will develop two other options that follow directly from the Eneev-Kozlov model. The first of these is the time taken for the accretion of the Earth from disk matter. This has been estimated at 10^4 to 10^5 years (Eneev & Kozlov 1979). The second is that, during the initial $0.5 \cdot 10^9$-year period of solar-system life, the Earth-type planets were bombarded by a hail of extremely powerful comets and asteroids derived mainly from the outer belts of asteroids, beyond Neptune (Eneev 1980).

CHAPTER III

Evolution of the Primordial Hydridic Earth to its Present Composition

In order to understand the evolution of the primordial hydridic Earth and to determine the causes of the planet's present unique characteristics, it is necessary to review some aspects of hydrogen-metal interactivities in various environments.

3. 1 The nature of the interactivity between hydrogen and metals:

Almost all metals can react with hydrogen. Metal interactivity proceeds first with adsorption of hydrogen on the metal surface, then as occlusions within the metal, and thence to chemical reaction and creation of hydrides.

Adsorption and occlusion are purely physical processes. With adsorption, a dissociation of hydrogen molecules into separate atomic nuclei occurs. With occlusion, the atomic nuclei give up their electrons, and the nuclei assume existences within the metal lattice in the manner of a proton gas. A single metal volume is able to occlude hundreds – even thousands, of hydrogen volumes. That the metal lattice is preserved, albeit with slightly altered characteristics, is evidence that no chemical reaction has occurred.

The third form of interactivity, chemical reaction between metals and hydrogen, produces the whole range of chemical compounds known as the hydrides. These compounds have new lattice forms in which hydrogen is chemically bonded to metals and is represented as hydride ion, "H^-," a proton and two electrons. The existence of hydrogen in ionic form, a hydride ion, as well as in the free proton state through occlusion, are proved today through extensive research (Mackay 1968; Galactionova 1967). A proposition made by Gibbs (1962) holds that the hydrogen proton in a metal lattice is an active form of the hydride ion.

Normally, the character of hydrogen interactivity with metals is varied. For some metals the final result of interaction is creation of adsorbed films; for others there is a volumetric occlusion. For still others, a powerful chemical reaction occurs, producing vast outputs of energy and creating solid-salt compounds, the hydrides.

The results of hydrogen occlusion in sodium, calcium, and magnesium, as well as in all base metals, are the ionic hydrides, which are solid crystalline compounds. Aluminum and silicon react with hydrogen to create polymer compounds similar to hydrocarbons. These compounds carry high stoichiometric quantities of hydrogen, and under standard conditions are liquids or gases.

When the amount of hydrogen is less, they may be crystalline compounds (for example Si_2H_2). Iron, nickel, and other "intermediate" metals do not form hydrides, but withstand the tendency of the more active metals to react chemically, while still being able to absorb and occlude hydrogen in volumes hundreds of times their own volume, especially under conditions of lengthy exposure to atmospheres of hydrogen. However, under pressures of 6 GPa and higher, all "intermediate" metals are transformed into hydrides (Ponjatovski et al. 1982).

The effects of pressure and temperature on metal-hydrogen interactivity behave oppositely. Increasing pressure stimulates occlusion and hydride formation. However, at much-elevated pressures hydrogen dissolves in metals at levels above stoichiometric equality. The opposite, the isobaric increase of temperature, causes dissociation of hydrides, a process in which the hydrogen ion transfers itself as an active proton gas in the metal, and then degasses as hydrogen from the metal. There is a specific minimum temperature for each individual hydride that must be reached before fast dissociation starts.

For example, the dissociation of calcium hydride appears to be intensive at temperatures above 600°C (Slavinski 1952):

Temperature:	°C	605	675	712	735	750	780	795
Dissociation pressure:	mm Hg	28.1	66.3	143.6	269.7	410	653.5	854

It is important to emphasize that high pressure considerably increases temperature stability of the hydrides. In fact, it may be said that for dissociation to proceed under conditions of increased pressure, there is a "requirement" for higher temperature (Mackay 1968).

Therefore, hydrogen-saturated native metals under high and super-high pressures probably exist only in the hydridic state. As increasing temperature causes the dissociation of hydrides, the hydrogen ions pass into the proton gas state while still dispersed in their metal hosts. Finally, increasing temperature expels them from the metals.

3.2   Metal purification by hydrogen:

Purification of metal by purging, the flushing of hydrogen through it, so to speak, has been used in the steel industry for more than forty years. Table 5 lists data on the changes to the composition of electrolytic iron after flushing with hydrogen for one hour at a pressure of 100 mm Hg (Hopkins et al. 1951).

Analogous behavior is experienced with other hydrogen-saturated, solid metals at high temperatures. In particular, an example is provided by the appearance of "flakiness" on metal castings after tempering by hot, mechanical working, an effect suggestive of surface oxidation as carbon is scrubbed from the hydrogen saturated zone of the metal. In another example, hydrogen flushing is known as an effective method for removal of oxygen from granules of chrome.

			TABLE 5		
THE COMPOSITION OF ELECTRIC ARC IRON AFTER PURGING WITH HYDROGEN					
	CONTENT: WT%			**CONTENT: WT%**	
IMPURITY	BEFORE PURGING	AFTER PURGING	IMPURITY	BEFORE PURGING	AFTER PURGING
OXYGEN	0.44	0.002	MANGANESE	0.008	0.004
SILICON	0.016	0.002-0.003	SULPHUR	0.006	0.004-0.006
CARBON	0.015	0.002-0.004	CHROMIUM	0.025	0.001
NITROGEN	0.010	0.001-0.002	ALUMINUM	0.001	0.001

3.3 Evolution of the Hydridic Earth

From this background it is possible to outline the evolutionary course to be expected for the internal structure of a primordially hydridic Earth. The basis for the following evolutionary sequence is determined by the traditional idea of initial radioactive heating. The Earth differentiated into its geospherical layers due to the fact that its interior hydrides became increasingly stable under conditions of the increasing pressure that accompanies increasing depth. Hydrides situated at the planetary center, where maximal pressure occurs, would have been preserved from dissociation for a relatively long time. Rather, the hydrides must have been encased in geospheres of metals saturated with occluded hydrogen. The saturated metals, in their turn, must have been encased within higher geospheres from which the hydrogen had been expelled.

Such was the evolutionary process that originated the hydrogen-bearing interior of our planet with its central hydridic core and metallic mantle. It is easy to recognize that the thickness of the mantle during geological history has expanded while the core has shrunk. The metallic mantle, flushed with hydrogen from the interior, would have been scrubbed and freed of oxygen admixtures in the manner of laboratory techniques. Escaping oxygen, in its turn, must have become infused into the minerals of the outer geospheres before it could escape into the atmosphere. That explains the outwardly-increasing silicate- and oxide-rich composition of the outer solid geospheres.

3.4 A new geochemical model of the Earth

On the basis of the forgoing reasoning, the author suggests a new geochemical model of the Earth, a model which is consistent with the latest geophysical data but completely different from current geochemical models.

The main differences between my model and traditional models is in the limitation of the silicate- and oxide-rich geosphere to depth ranges of no more than 350-400 km under the continents and even less under the oceans. My view is that the major portion of Earth's volume is non-oxidic and mainly silicon and magnesium metal, but also incorporates iron and coactive calcium, aluminum, sodium, and other elements in lesser quantities. All

these constituents in the outer core contain dissolved hydrogen, whereas in the inner core they are present as metal hydrides.

			TABLE 6
A NEW GEOCHEMICAL MODEL FOR THE EARTH			
SPHERE	**ZONE**	**DEPTH: Km**	**COMPOSITION**
Crust	A	0 - 33	silicates and oxides
	B	33 - 400	
Mantle	C	400 - 1000	metals
	D	1000 - 2900	
Core	E	2900 - 5000	metals with dissolved hydrogen
	F	5000 - 5100	
	G	5100 - 6371	hydrides

Here one might appropriately call to mind the popular aphorism that the "new" is nothing other than the well-forgotten "old." Indeed, in the nineteen-thirties, taking stock of the major role of hydrogen in our Universe, V.I. Vernadski wrote the following words with regard to the internal composition of the Earth:

"Our understanding of the thermodynamic and chemical conditions in the deepest zones of our planet compels us to regard them as hospitable to hydrogen compounds. Chemical activity wanes; oxygen content abruptly declines to zero; the siderophilic metals commence to be dominant; and, most likely, there is increasing hydrogen. At the same time, pressure and temperature rise, conditions characteristic of the depths, which should contribute to the preservation of hydrogen compounds and the dissolution of hydrogen in metals as well." (Vernadski 1960)

The complete congruence between the author's conclusions and Vernadski's theorizing permits treating the hypothesis of a primordially hydridic Earth as a natural continuation of Vernadski's ideas. This reference to my illustrious compatriot was not made to bask in the brilliance of his reputation. It will be remembered that in his day all such ideas verged on intuitive speculation. That was also a time when open expression of alternatives carried no risk to their author's reputation. Put another way, during Vernadski's time, the concept of the "iron core and the silicate mantle" had not yet become canonized dogma. That development would come in the subsequent decades, notwithstanding that it has never been proved.

CHAPTER IV

Mantle Physics and Earth Models

4.1 Oxidic composition and the physics of the mantle

Today, as a result of seismic exploration, the detailed structure of the "C" zone of the upper mantle has been determined. Seismic-wave travel in the "C" zone is shown to have a profile containing three planar zones of rapid velocity change. These occur at depths of 400, 650, and 1050 km (see Figure 5). This result was not unexpected, because as early as the 1930s K. Bullen, an investigator into numerous models of the spherical distribution of Earth's density, found that the proper value of the Earth's moment of inertia was satisfied only by a model that assumed an anomalous increase in mantle density at intervals between 400 and 1000 km depths.

Bullen's research fostered an hypothesis, which was outlined in 1936 by J. Bernal. His suggestion was that within the mantle an olivine transformation occurred in which a mineral with a spinel structure and 11% greater density was created. That led to the idea of a transitional layer within the mantle. Thus, the olivine-spinel transformation was an idea born during the 1930s.

Experimental checking of the feasibility of the olivine-spinel transformation took many years. Encouragement to research was provided by the fact that even before the existence of modern, high-pressure equipment, the polymorphism of germanides (compounds of tetrahedral germanium oxide), were recognized. In these compounds, which have a silicate isomorphous structure, phase transition commences with a relatively small increase in pressure. Based on the evidence provided by this mineral, an olivine-spinel transformation model was created with a critical pressure of about 4 GPa.
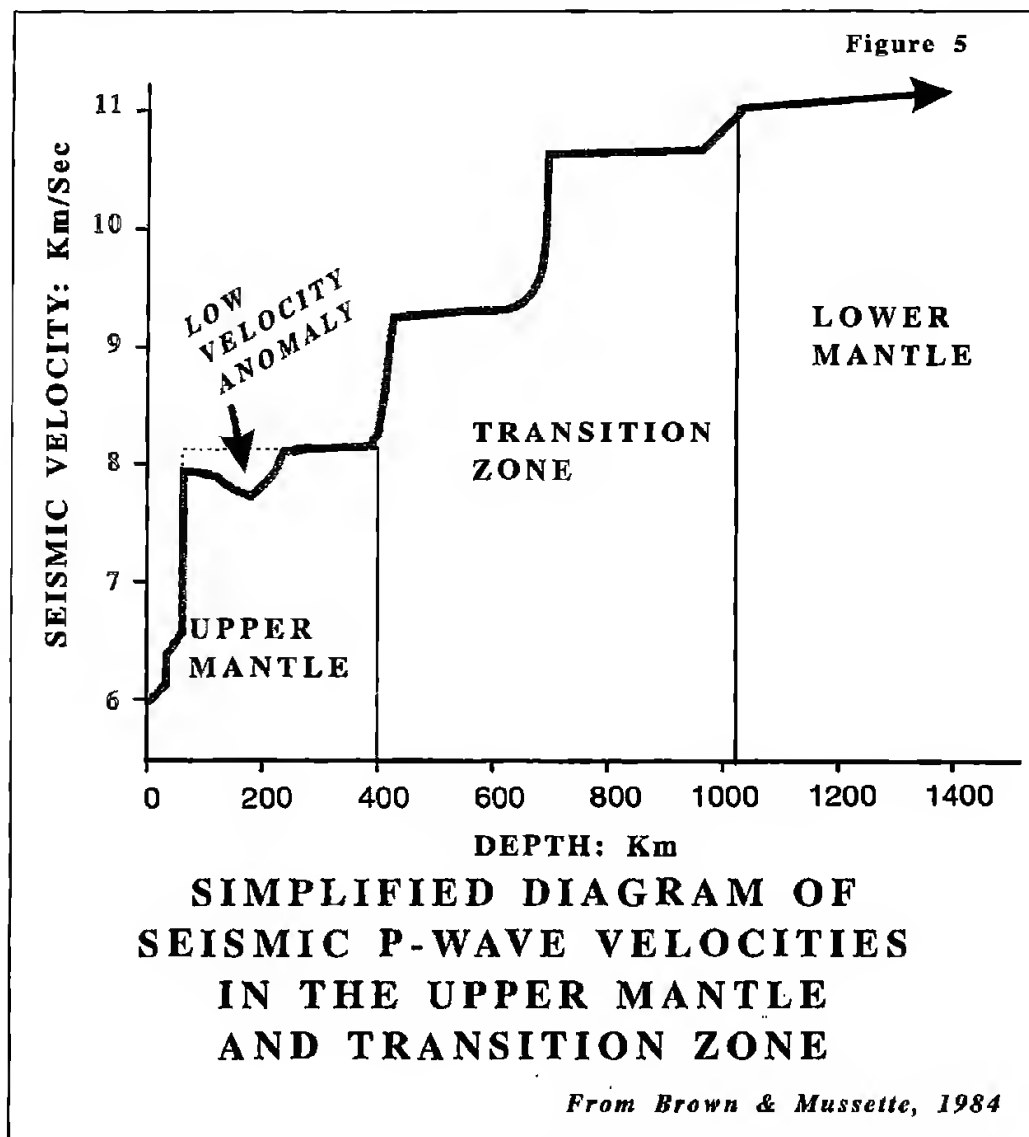
A phase transition in the silicate, fayalite (Fe_2SiO_4) was discovered in 1958 by A. Ringwood. Then finally, ten years later, the transition was recorded for olivine with a mantle content of the forsterite molecule (Mg_2SiO_4). The leading researchers in this area were Australian scientists, A. Ringwood and A. Madjer, and also Japanese scientists led by S. Akimoto.

The olivine-spinel transformation is sensitive to temperature and pressure. For example, if the temperature is 1200°C, the transformation starts at a pressure of 12.5 GPa (approximately equivalent to a depth of 370 km). When the temperature is 1600°C, the necessary pressure is now 13.5 GPa which corresponds to a depth of 400 km.

There are some current ideas on possible phase transformations that may occur at the deepest seismic discontinuity, that found in the depth range of 650-700 km at pressures from 23 to 25 GPa. One theory suggests compression of the spinel phase into ilmenite or perovskite structure. Another suggests a possible transformation of garnet into a mineral with ilmenite

structure.

Data acquired from the deep electromagnetic surveys show an abrupt

Figure 5

**SIMPLIFIED DIAGRAM OF
SEISMIC P-WAVE VELOCITIES
IN THE UPPER MANTLE
AND TRANSITION ZONE**

From Brown & Mussette, 1984

increase of mantle electrical conductivity, four to five orders of magnitude, in fact, occurring in the depth interval 300-400 km (Rikitaki 1963). It has been shown, furthermore, that this sharp increase is not due to increase of ionic conductivity in silicates subjected to elevated temperature. Increased ionic conductivity is quite impossible, because the high pressure restricts ionic mobility in a silicate crystal lattice (Lyubimova 1968).

Besides, if the elevated electrical conductivity is brought about by phase transformation [such as the olivine-spinel case], this would signify that a particular pressure, and conductivity at the top of the mantle should be associated with a particular depth, a situation that is not found to be true. The conductivity transition occurs at various depths. Significantly, for example, in Texas (USA) within a horizontal distance of 400 km the transition changes abruptly

from a depth of 320 km to 160 km (Rikitaki 1972).

The assumption may be made that the abrupt elevation of this boundary results from phase transformations brought about by decreased mantle temperatures. But in this particular case the mantle conductivity discontinuity is elevated and, heat emission at the surface is also elevated with respect to surrounding terrain. This is exactly opposite to expectations. Furthermore, the electrical conductivity in the mantle is shallowest beneath the oceans. According to Cox (1966), it occurs at 75-100 km, depths insufficient to provide the pressures necessary for the olivine-spinel phase transformation.

Currently, one is able to list many facts that are difficult to explain on the basis of a silicate composition for the entire mantle. Some of these facts are as follows:

1. The upper limit of the conductive mantle does not coincide with the seismic discontinuity.

2. Increase in mantle electrical conductivity of five orders of magnitude can hardly be explained in terms of the olivine-spinel transition – it is dubious logic to try. An additional question is raised if one considers the thermal conductivity of the mantle. Calculations made by a number of researchers imply that the thermal conductivity of the mantle must be greater than that presently interpreted in traditional thinking, and that, without this elevated conductivity, the mantle could not avoid melting.

3. Seismic investigations have determined only three velocity discontinuities in the transition layer, whereas research conducted on mantle mineral assemblages has discovered approximately ten phase transitions.

4.2. The new Earth model and mantle physics

There is no need to create a special explanation for the marked increases in thermal and electrical conductivities that follow exchanges of the metallic components of silicates and oxides. Whereas silicate minerals would normally act as thermal and electrical insulators, a composition for the mantle of metallic nature ("intermetallic"[1]), rather than a silicic or oxidic one, would allow elevated thermal and electrical conductivities. The most likely intermetals are the compounds, Mg_2Si, $FeSi$, and native metal, Si. All of these are semiconductors. Mantle has semi-conductivity that is less by six orders of magnitude than the conductivity of true metals, however, and I suggest the actual conductivities are explained by the presence of the semi-conductive intermetallic compounds and silicon.

Thus, in my model the surface of "conductive" mantle corresponds to the base of a silicate-oxide planetary shell. This new model explains the specific makeup of layer "C" as silicon-polymorphic. It has been shown that in specific pressure intervals silicon undergoes polymorphic transitions with corresponding increments of density, as follows:

11.2 - 12.5 GPa :	**20 %**	
16 - 16.5 GPa :	**3 %**	
35 - 40 GPa :	**5-6 %**	*(Olijnyk et al. 1984)*

The pressures represented by the foregoing table were obtained at

room temperature, which is not representative of the mantle transition zones. In the Earth temperatures increase with depth. The law that defines the slope of the temperature-dependant boundary separating phase changes (dP/dT) is presently unknown. Usually there is increased pressure with increased temperature; and if temperatures at depths of 670-700 km reach 1,500°C, then the gradient, $\partial P/\partial T$, at the second transition for Si in the mantle is not exceptionally high, and may, in reality, be quite appropriate for phase transitions of similar type.

What then happens to density? Silicon can be compressed to double density under a pressure of 50 GPa. (see Fig. 6). Therefore, at a depth of 1250 km its density should be 4.66 g/cm^3 . Mantle density at the same depth, based on Bullen's geophysical model, is 4.67 g/cm. However, we still do not know the nature of Mg_2Si compressibility. One should expect a first order polymorphic transition, which should take place when the pressure reaches 6 GPa (Dugeva et al., Institute of High Pressure, Moscow). The condensed phase of this compound has a density of 2.30-2.35 g/cm^3 at room temperature and pressure. It can be generated in the laboratory and is [surprisingly] preserved under normal P-T conditions. The density of the FeSi phase under standard conditions is 6.16 g/cm^3. Unfortunately, there are no data on its compressibility.

It is extremely important that exploration on the compressibility of the Mg_2Si and FeSi phases be carried out using modern high-pressure equipment, whence the results can then be compared with observations from geophysics. It is also necessary to determine the phase makeup of the anoxic mantle, which quite possibly may be far more complex than the dual-component systems that we are accustomed to promulgate in experimentation.

Some research scientists are sceptical of my interpretation of "conductive mantle," because of the low melting temperature, 651°C for magnesium. Their calculations, which have been carried out with the necessary adjustment for pressure, show that there would be melting at zone "C." On the other hand, and in defense of my interpretation, it is highly probable that our planet has an anoxic mantle of magnesium acting as an intermetallic compound, Mg_2Si, which has a melting temperature of 1100°C at standard pressure.

Seismic wave velocity data exhibit unusual features in the zones above and below the discontinuity at 400-km depth [zone "C"]. The gradient of increasing velocity below the discontinuity is significantly higher than above it. From this it can be concluded that, after polymorphic transformation has occurred, and matter is at higher pressure, its compressibility increases.

To resolve the velocity enigma within the framework of traditional theory geophysicists have been forced to accept the existence of an "expanded" zone of polymorphic transition, which varies as a function of pressure – e.g., the transformation from diopside and jadeite to garnet, which is aided by elevated pressure (Anderson 1982).

Relative to our interest in zone "C," the same speculation is still

possible. However, it is important to remember that, during phase transformations of "dielectric $\Rightarrow$ metal" and "semiconductor $\Rightarrow$ metal," the denser metal phase may be compressible to a higher degree, because of the transposition of the outer electrons that follows from the disruption of the rigid covalent junctions in crystal lattice structures. In particular, this behavior is observed in the metallization of silicon, but also with compounds such as SnAs, MnF_2, and others.

Figure 6

THE POLYMORPHIC
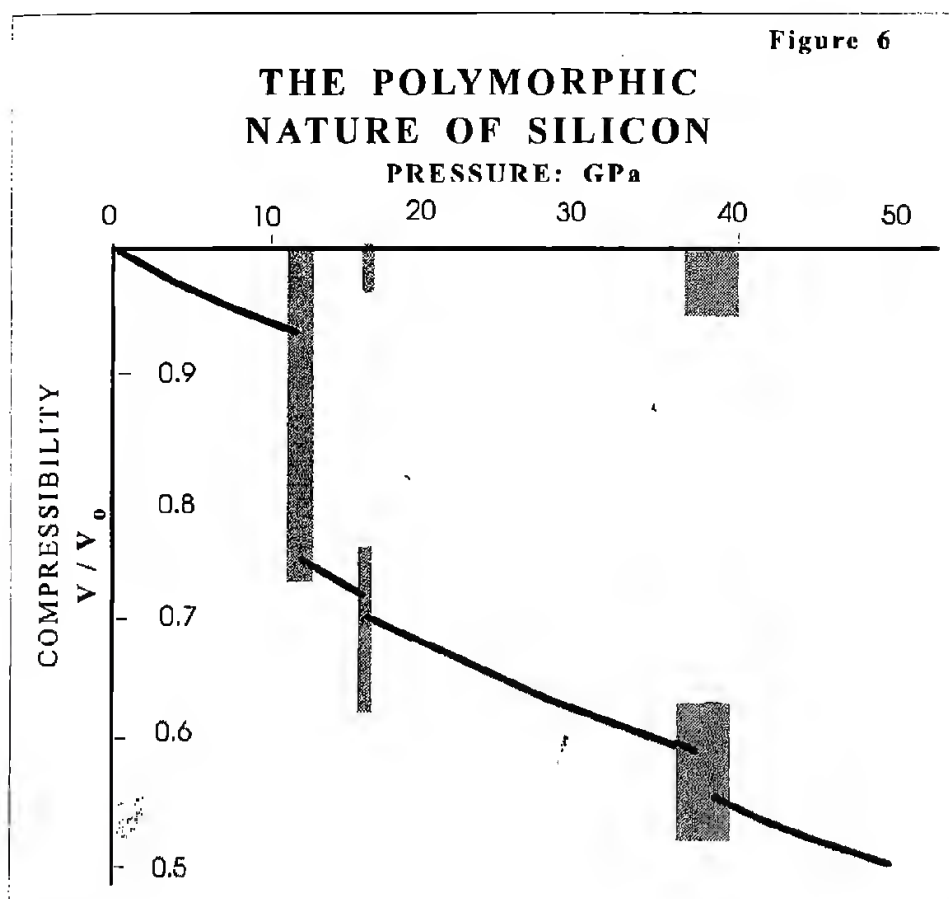## NATURE OF SILICON
PRESSURE: GPa

Figure 6 shows three discontinuities in the curve representing the compressibility of silicon at room temperature. They were found in the course of experimentation with a diamond anvil (Olijnik et al. 1984).

In particular I have observed that in the transition of Mg_2Si to a denser phase metallization is attendant in a fact of primal importance, the process. Unfortunately, during experimentation, it was impossible to maintain an exclusively hydrostatic pressure, a problem which was due, accòrding to Dugeva et al., to the transition itself taking place at reduced pressure. In this case it can only be confirmed that the actual pressure at which the phase transition of Mg_2Si takes place is greater than 6 GPa. In these experiments it was possible to record the existence of two-phase states up to 10 GPa, the limiting pressure in the experiments. Thus, we are permitted the deduction that metallization of Mg_2Si under internal Earth conditions occurs at 10 GPa

and greater pressures. Therefore, when we take into account the increase in transition pressure that accompanies increased temperatures, it may be deduced that Mg_2Si exists in the mantle "C" zone as a metal.

This model explains not only the detailed nature of zone "C" but also the reason for declining gradients of compressibility and gradients of seismic velocity in the mantle at zone "D." These phenomena are related to the intrinsic nature of metals and silicate-oxide minerals. Under pressures of 40 GPa and higher, the depth equivalent of zone "D," metals show a abrupt decrease in the compressibility gradient as well as the rigidity module. Such occurrences do not take place with silicates and oxides (Figure 7).
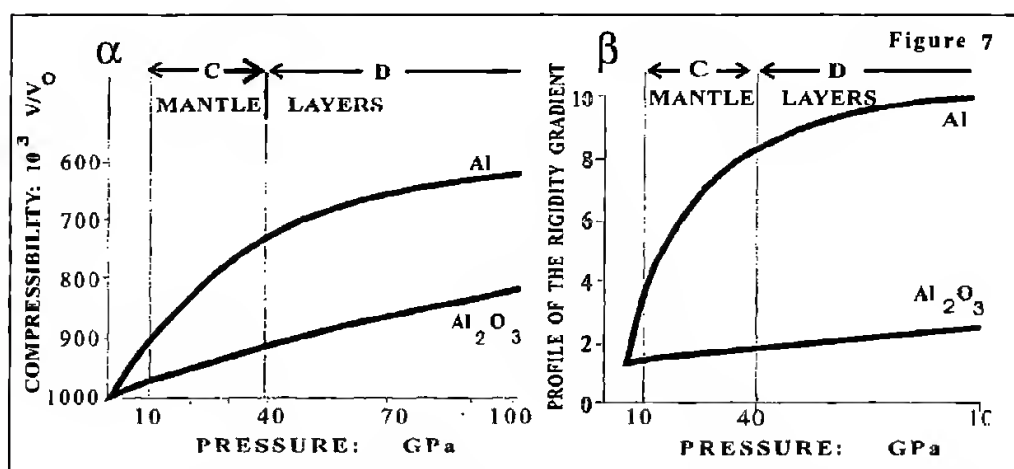
α - COMPRESSIBILITIES OF METALS AND THEIR OXIDES

β - THE VARIATION OF YOUNG'S MODULUS IN METALS AND
THEIR OXIDES

From Birch 1969

CHAPTER V

Physics of the Core

and

Geochemical Models of the Earth

The transition between Earth's mantle and its core, according to current doctrine, comprises an abrupt density increase (approximately 70%), a sharp drop in seismic compressional wave velocities, abrupt opacity to secondary sonic waves, and enhanced electrical conductivity. Analyses of tides in the crust, diurnal nutation of Earth's axis, and the non-transmissibility of secondary waves suggest a liquid state for this outer shell of the core (Gutenberg 1963; Pariisky 1963; Magnitsky 1965). Despite the abruptness of the interface, there is still reason to believe that it spans dozens of kilometres (Vinnik & Dashkov 1970; Bolt 1973).

The implications from seismology are that the inner core is solid, a condition attributed to higher pressures along with a relatively low internal temperature gradient.

5.1 Problems of the iron core

The hypothesis of the iron (and/or iron-nickel) core is based on a universally known fact that iron is the sole heavy element widespread on Earth and in meteorites. Whereas the hypothesis accounts for high density and high conductivity in the core, application of the theory encounters serious obstacles elsewhere.

The equation describing the states of iron is presently well known for pressures up to the values applicable to the core [Zharkov & Kalinin 1960; Davydov 1956). As a result, assuming the core is iron allows derivation of core temperatures from pressure and density data. However, according to Magnitsky [1965], the values obtained seem improbably high, being as much as 11,000°K at the center of the Earth. Working with shock compressibilities,

MacDonald and Knopoff (1958) established that the density of a pure iron core would be higher than the observed value. From this experimental work the core is deduced to contain at least 10-15% of light impurities (silicon, sulfur, magnesium, oxygen, or other light elements). This contamination renders determination of core temperature impossible.

Core theory is stalled, therefore, in gridlock over attempts to interpret the mechanisms responsible for its formation. Had the core resulted by differentiation from an initially-uniform Earth, the process would have released a quantity of energy[1] sufficient to cause complete melting of the planet. In that case, if we take into account Earth's rate of heat release, the entire mantle beneath 50 km must still be molten (Maeva 1971). These results fail to accommodate the seismic data and argue against the hypothesis of the core being a product of gravity-induced differentiation in the bowels of the Earth.

To avoid these complications some workers have assumed the existence of a high, primordial heterogeneity for the Earth, even to the extent of allowing for core formation during planetary accretion. This scenario, however, fails to stand up to thoroughgoing analysis of the sequence through which condensation of protoplanetary substances must have taken place (Anders 1968). *Silicate particles appear to have preceded iron.*

Finally, the iron-core hypothesis fails to account for the regularity among the terrestrial planets of the relationship between density and planetary size. The larger the planet, the higher its density, due to greater total iron content. Mercury is an exception to this rule.

5.2 A metallized silicate core

Another hypothesis suggests that high density and electrical conductivity of the core should be associated with a phase transition from silicates and oxide minerals of the mantle to a metallized state brought about by extreme pressure (Ramsey 1949). On the face of it, this hypothesis seems to avoid many drawbacks of the other theories. Furthermore, it implies a simple explanation for the origin of the core. Specifically, the existence and size of a planetary core are taken to be related to the overall mass of the planet. It then becomes clear why large planets [like the Earth and Venus] have a core, whereas the Moon or Mars do not. However, this hypothesis fails in the case of Mercury, the high density of which implies a large core that is disproportionate to the small size of the planet. In addition, shock compression experiments (Altshuler & Kormer 1961; Paul & Warshaner, 1963) involving pressures higher than those at the center of the Earth, show that silicate metallization

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[1] *Through recognition of the potential energy of heavy particles.*

in the core is impossible and not a feasible option to achieve the required volume reduction of nearly 50 percent. This is because "... silicates are not open structures, when the electron shells of their oxygen anions are completely occupied" (Zharkov & Magnitsky 1970). The silicates, for this reason, are markedly restricted in their capacity for compaction.

Finally, it is completely unclear why silicates at the core boundary should melt as an adjunct to compaction. Thus, we are left to guess why there should be a fortuitous coincidence of the melting front in the core with the silicate-oxide phase boundary. If the geophysical data are taken at face value, the existence of even a thin, solid-phase layer between the core boundary and its liquid phase (Balakina & Vvedenskaya 1962) is highly improbable (Magnitsky 1965).
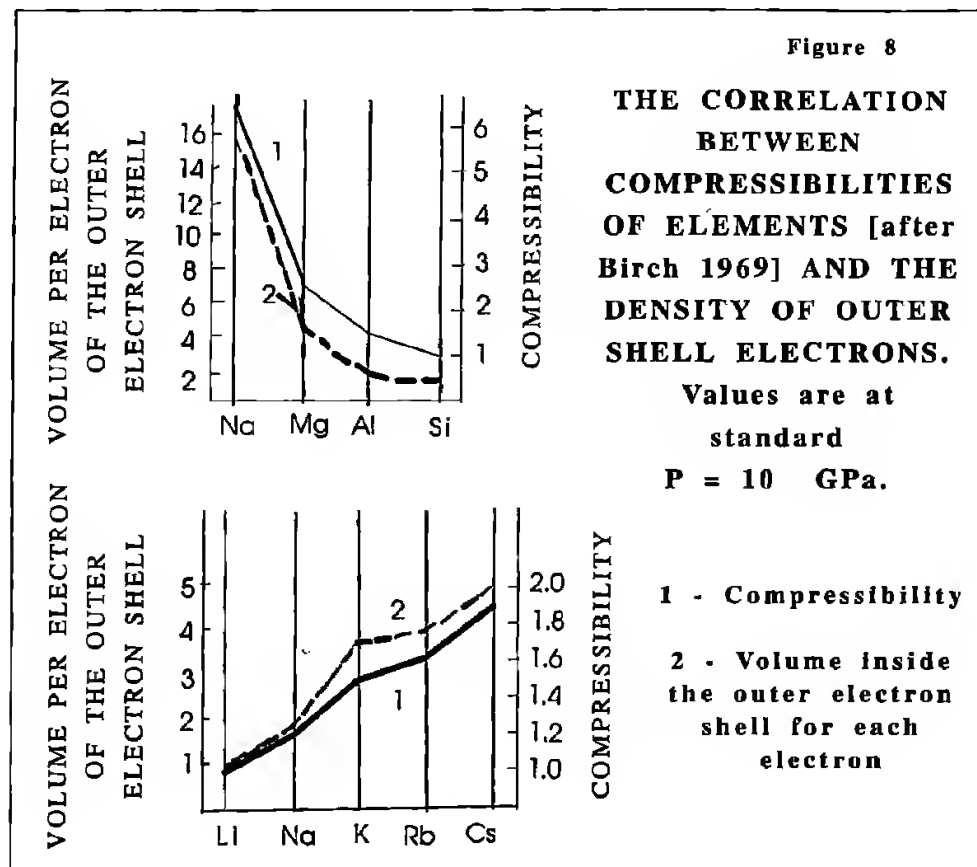
5.3 A hydrogen-bearing core and its physics

5.3.1 Compressibility of hydrides and the inner core

No direct experimental data on compressibility of hydrides in a mega-bar range of pressures are available.[2] However, the state-of-the-art in this field allows for some substantial extrapolation. Compressibility of crystalline bodies is possible, on the one hand through the compaction of lattices when they transform to denser crystalline forms, and on the other hand through compaction of atoms themselves. Because metals have densely packed lattices by comparison with salts and oxides, any significant compaction must occur within their specific atomic structures. Significantly, it is the open character, the vacant space in the outer electron shell that is primarily responsible for the physico-chemical properties of metals.

There appears to be a distinct correlation between the compressibility of particular metals and the openness of their outer electron shells; more openness correlates with more compressibility. This relationship is shown unequivocally in the graphs in Figure 8. Interestingly, the compressibility line in the graphs delineates the property of openness of the outer electron shell in metals. This correlation is evidence for a close causal relationship between these properties.

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[2] *Attempts were made to determine the density of calcium hydride (CaH_2) over a mega-bar range of pressures by the shock compression method. However, the compound is chemically unstable, and there is nothing to assure us that it was not decomposing ahead of the shock wave, which imparts an extremely powerful "thermal shock.." In addition, calcium hydride is known to convert in free air rapidly to an hydroxide; and the procedures of the experimentation did not provide for it to be carried out in an inert atmosphere. Thus, it is impossible to be sure that the results report the true compressibility of calcium hydride. Apparently, reliable results in this case are obtainable only with compression under static conditions.*

Figure 8

THE CORRELATION BETWEEN COMPRESSIBILITIES OF ELEMENTS [after Birch 1969] AND THE DENSITY OF OUTER SHELL ELECTRONS. Values are at standard P = 10 GPa.

1 - Compressibility

2 - Volume inside the outer electron shell for each electron

To gain a better picture of the open shells in metals, it may be useful to draw attention to the properties of cesium: its single outer electron shell has a volume several times that of all the remaining 54 electrons. Whereas we might suppose that such a vacancy in an outer shell would lead to multifold compressibility with pressure, the experiments of Birch (1969) indicate an abrupt decline of compressibility at pressures of about 10 GPa. Apparently, compressibility is limited by rapid growth of repulsive Coulomb forces as the outer shell collapses against inner electron shells that are fully occupied and exhibit virtual incompressibility.

Figure 9

A THEORETICALLY-POSSIBLE
ARRANGEMENT OF HYDRIDIC
IONS IN A TRANSFORMED LATTICE

α

β

At very high
pressure

At standard pressure
of one atmosphere
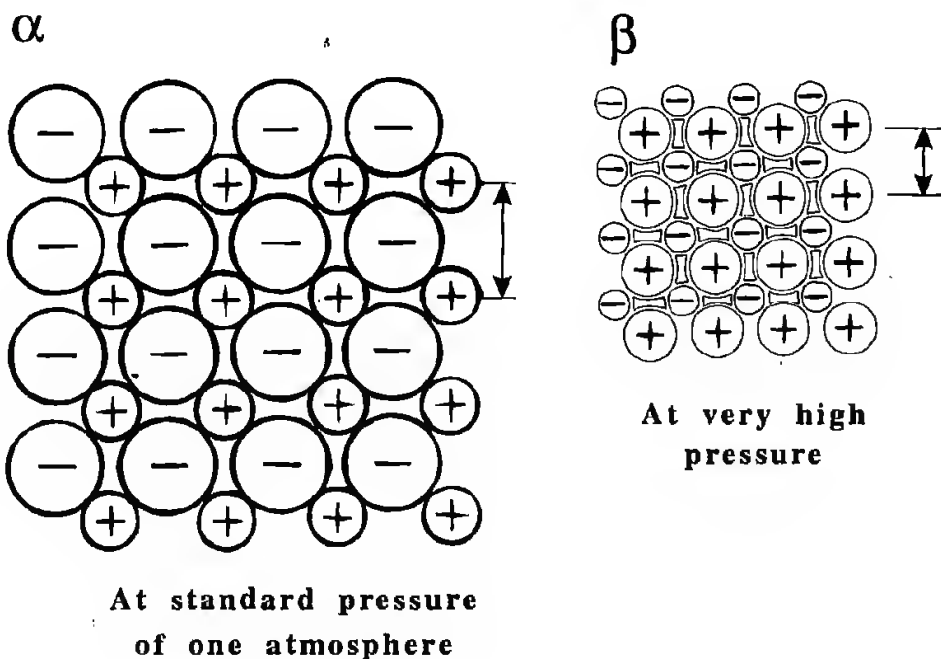
As in metals, there is a relative vacancy in the electron shell of hydrogen. It is this unique feature that distinguishes hydrogen from the rest of the elements and results in its exclusive compressibility behavior. Absence of inner electron shells permits multifold compaction of the sparse electron cloud of elemental hydrogen as well as the hydride ion. It is possible in principle that under extremely high pressures, electrons of the hydrogen ion will be forced into orbit as near as possible to the nucleus. This should lead to a multiple compaction of the hydride lattice, which will, thusly, be transformed into most-closely packed metal cations interspersed with multiply-compacted hydride ions (Figure 9). Because the ionic radii of metals on average are about one-half as large as their respective atomic radii, hydrides under extremely high pressures can be compacted as much as 8-fold.

Figure 10

DENSITY
VARIATIONS IN
POTASSIUM (K)
AND ITS
HYDRIDE (KH)
OVER WIDE
RANGES OF
PRESSURE

*Potassium
compressibilities
are taken from
Birch et al. 1969.
Hydride
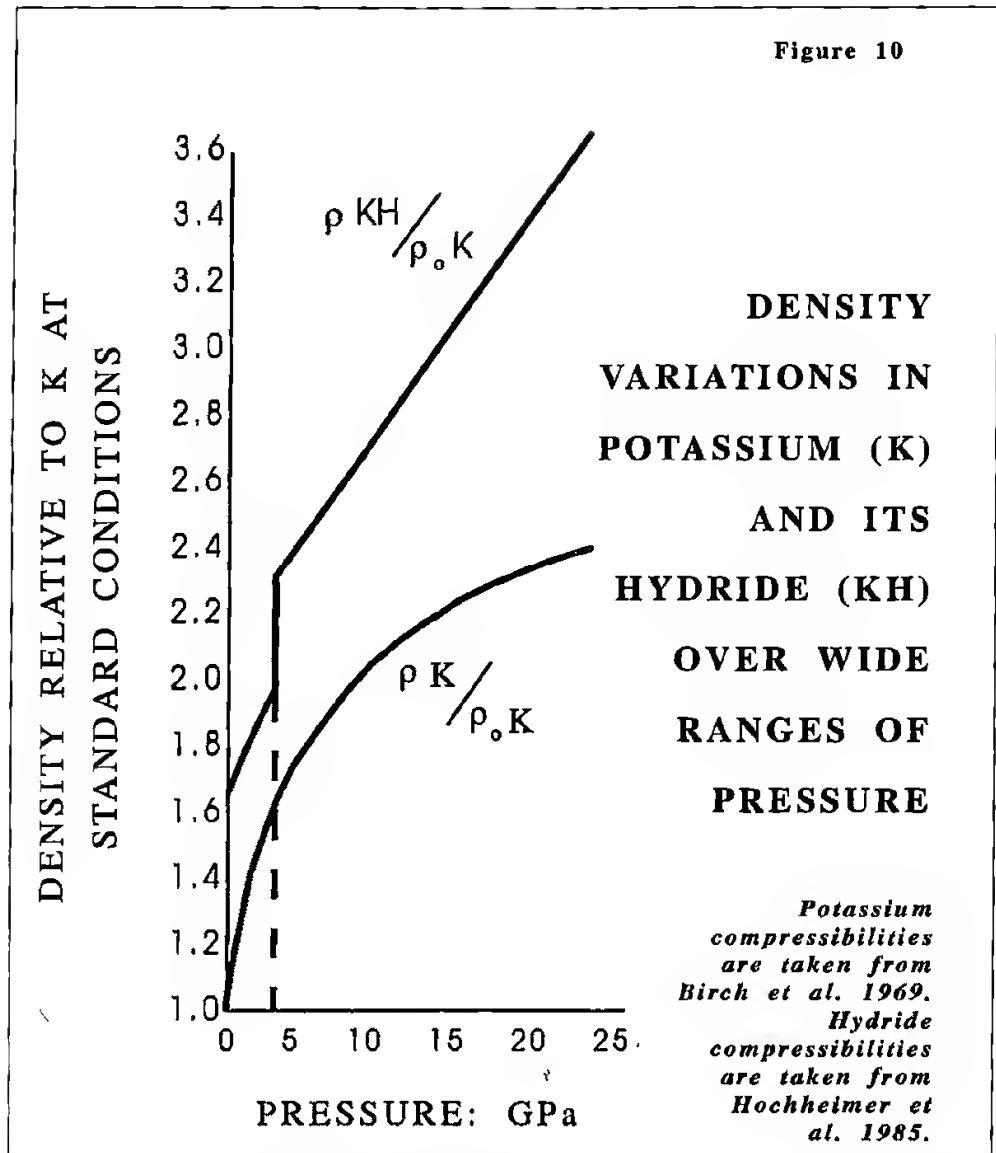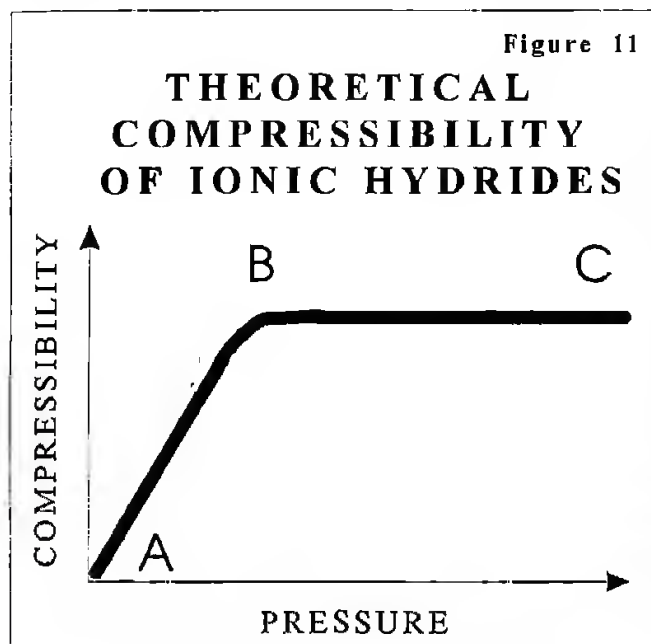compressibilities
are taken from
Hochheimer et
al. 1985.*

Figure 10 illustrates the compressibility of potassium (K) and its hydride (KH) normalized to the density of K at standard conditions. The compressibility discontinuity of KH is due to phase transition. Where K compression converges asymptotically on a limit and is unlikely to triple with further pressure increase, KH density increases 3.5-fold to 25 GPa with no suggestion of a gradient decrease. Ionic hydrides are the only known forms of matter with unvarying compressibility gradients that may range up to hundreds of thousands of atmospheres (n×100,000 atm), a characteristic that is attributable to their lack of inner orbital electrons.

Figure 10, in comparing the compressibility of potassium and its compaction in the form of a hydride over a wide range of pressures, establishes the compressibility gradient of the metal at pressures above 7.5 GPa and shows it converging progressively toward an undetermined asymptote. The reduction is the effect of repulsive Coulomb forces. The compressibility of potassium hydride through the same pressure escalation is, surprisingly, constant and high! Thus, the anomalous compressibility of which the hydride anion is capable, is ultimately suggestive of a transformation of the ionic hydride lattice from type "a" to type "b" (see Figure 9)

Ultimately, the hydride character that may result from compaction at high pressures is plotted in Figure 11, where the AB segment corresponds to the compaction of hydride ions proportionate to applied pressure. The region of inflection B defines the region where the hydride capacity for compaction is terminated by the direct contact between the dense electron shells of metal cations.

Figure 11

THEORETICAL COMPRESSIBILITY OF IONIC HYDRIDES

Another example of the anomalous compressibility of the hydride anion is the divergence of the densities of the ionic hydrides at standard conditions (1 bar) and those of the native metals. It is a seeming paradox that metals absorb hundreds of volumes of hydrogen into their respective volumes without swelling. But they do become denser, their atoms within the crystal lattices being compacted! (Table 7). This compaction takes place not through addition of hydrogen atoms to the metal lattice, but to the creation of a hydride lattice, which has less space between metal atoms than the original metal lattice. The cause of this behavior is an *electrostatic (cation - anion) collapse into ionic hydride lattices.* The readily-compressible hydride anions in the lattices are deformed, thus reducing interatomic distances.

TABLE 7

COMPACTIBILITY OF METALS IN THE IONIC HYDRIDE STATE AT STANDARD CONDITIONS

DENSITY g/cm^3	LiH	NaH	KH	RbH	CsH	CaH$_2$	SrH$_2$	BaH$_2$
Metal	0.534	0.971	0.862	1.532	1.903	1.55	2.60	3.50
Hydride	0.816	1.396	1.43	2.59	3.42	1.90	3.26	4.21
Compaction (%)	52.8	43.6	65.8	69.2	80.0	22.6	25.4	22.9

Metals in elemental form are amenable to compaction up to the values shown in Table 7 by the simple application of pressures of 5-10 GPa or more. Compressible metals in the hydride form do not include magnesium or silicon despite the fact that those metals are abundantly distributed in the planetary body. Their hydrides have notably more openness than the native metals and hence, lower densities.

Densities of the metal hydrides depend on the predominant type of bonding. For mainly ionic bonding, the hydrides prove denser than native metals. For bonding that is predominantly covalent, the hydrides are less dense, because they lack any electrostatic, cation-anion lattice compaction.[3]

Bonding type may vary in response to external conditions. Under low pressures, bonding is dependent on the electronegativity inherent in each element. At mega-bar pressures, volumetric effects become the dominant thermodynamic driver, and reactions proceed in the direction towards higher density amid coexisting phases. Hydrogen-bearing metal compounds deep in the interior of the planet are more likely to be ionic hydrides, because under these conditions the anomalous compressibility of the hydride anion is fully implemented. Furthermore, the high density of the inner core, and its solid state can permissibly be related to the anomalous compactibility of hydrides through deformation of hydride anions.

5.3.2 Metals containing dissolved hydrogen, and the outer core

There are several hypotheses on the form taken by occluded hydrogen in metals. Earlier concepts postulated that hydrides are formed with low stoichiometric concentrations of hydrogen. Some scholars allowed for solid solution of hydrogen in metals by means of formation of "penetrative phases." However, subsequent thorough examinations of X-ray structures failed to support these theories (Galaktionova 1967).

Experimental data, on the other hand, fully substantiate the hypothesis that hydrogen is present in metallic lattices as atomic nuclei, single protons, which have penetrated the outer electron shells of metallic atoms. Substantiating this interpretation are experiments conducted by A.I. Krasnikov, which showed a hydrogen-induced reduction of doublet separations in the outer electron shells of a large group of metals. This reduction could not be interpreted from any orthodox or universally accepted point of view, but became understandable as "proton gas" within metal atoms (Krasnikov 1946).

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[3] *Calculations showed that even among the salt-like hydrides of the alkaline metals, the type of bonding has an intermediate ion-covalent character, which leads to only 30 - 50% ionic bonding (Galaktionova, 1967)*

Later it was shown by Galaktionova (1949) that with hydrogen dissolved in the solid and liquid steel, the doublet separation decreases proportionally to the amount of dissolved hydrogen. Additionally, under the effect of weak electrical fields, hydrogen in liquid metal migrates toward the cathode. This migration can occur only if the hydrogen is in the form of protons (Yavoiskii 1955). A similar phenomenon is observed in solid metals (Mackay 1968).

The presence of dissolved hydrogen in the proton form is supported by extensive experimental data, which define the functional relationship between hydrogen solubility and electrical conductivity in metals, and the effects of hydrogen on the magnetic and mechanical properties of metals and alloys (Galaktionova 1967). Additionally, the proton state of dissolved hydrogen is evidenced by its property, exclusive among the elements, of mobility in metallic environments [an atom of hydrogen is considered incapable of such migration, because of size]. And lastly, the proton state of hydrogen dissolved in metals is apparent in NMR spectra (Mackay 1968).

These considerations conform well with the specific configuration of the atomic structure of hydrogen. Its ionization yields a single proton with an effective dimension of about 10^{-13} cm, that is to say, 0.00001th the size of most metal atoms. There is no proper parallel between hydrogen and other elements such as nitrogen or carbon, whose Their atoms, even after they lose outer electrons, retain their sizes within an order of magnitude. Only hydrogen can enter metals to create structures by penetration or replacement.

Small effective size and large concentration of charge and mass allow protons to penetrate through the innermost electron shell of a metal and to trigger first-order change in the physical nature of the atom. The penetration is necessarily due to the distribution pattern of electrons in metal atoms, the outer electron shell normally taking up the outer half of atomic radius, the rest of the electrons being densely packed into the inner half. Such inner compaction of electrons compensates the charge of the nucleus, and virtually eliminates the Coulomb barrier for the outer half of the radius in metal atoms. In addition, the proton belongs to a class of elementary particles and, hence, possesses a specific wave character that affords it a tunnelling capability to penetrate the Coulomb barrier and deep within the sub-barrier region. This osmotic effect, penetration of the particle through the charge barrier, takes place in conformity with quantum mechanics without addition of energy from any outside source. The phenomenon has two important implications.

First, deep penetration of protons into electron shells is tantamount to an abrupt increase in the effective charge of the atomic nucleus of the metal. Consequently, the atomic radius is diminished. At standard temperature and pressure and low hydrogen saturation this behavior does not induce

significant metal compaction. Lattice parameters remain unchanged and the only noticeable effects are diffuse diffraction patterns, which suggest development of stress in the lattices. However, under conditions where pressures of 100 GPa or more prevail, where temperatures are high enough to effect complete protonization of hydrogen, where hydrogen saturates a metal at H:Me mol ratios close to one, the metal is subject to extreme compaction.

Second, a tendency toward reduced atomic radii will lead to the reduction of the potential barrier that obstructs the passage of the atom into neighboring interstitial sites and limits its internal mobility. In other words, enhancing atomic deformability (the effect of intruded protons) should remove much of the resistance to diffusive activity. At some point under conditions of high temperature and hydrogen saturation, the interatomic mobility of atoms can be boosted to a state more akin to a viscous liquid than a solid body. This should occur in a temperature range far below the melting of metals.

Now we shall go back from the subatomic world to the Earth's interior. Our geochemical model helps to explain the liquid state of the outer core, the abrupt change of density at the core-mantle interface as a result of the compaction and "liquefaction" of metals by protonized hydrogen. In addition, the solitary-proton atom, hydrogen, provides a source of additional electrons for the zone of metallic conductivity (Mackay 1968), thus, easily accounting for the high electric conductivity of the outer core.

A discussion follows in Chapter X showing how the new theory relies on the orderly interdependence between planetary densities and masses, in contrast with existing hypotheses, which attempt to explain away the solid state of the inner core by tinkering with additives and artfully manipulating the geothermal gradient.

5.3.3 Experimental verification of "liquefaction" of metals by hydrogen "proton gas"

Speculations on metal liquefaction by proton hydrogen are critical for the new model; and special experiments to verify the hypothesis have been carried out. The results substantiate that dissolved hydrogen does, in fact, raise the malleability of metals by reducing resistance to interatomic movement. Abnormally high plasticity (even super-plasticity) of metals should be attainable. This conclusion has provoked adverse comment from experts in solid-state physics, whose expertise implies the opposite: when metals are penetrated by hydrogen, they are always embrittled, often with catastrophic results. Certainly this phenomenon, which is beyond our experience, implies that

crystalline lattices of metals, even monocrystalline samples, must be interspersed with vacancies, dislocations and grain boundaries at low angles of incidence. Within these gaps hydrogen can recombine from protons to its atomic or even molecular state as well as create compact adsorption films on inner surfaces. This renders the metals passive and leads to embrittlement by severely limiting the propagation of dislocations.

However, under conditions of extreme compression, these numerous cracks are sealed. Thenceforth, at some level of pressure, hydrogen must, of necessity, be present in the lattice exclusively as a proton gas. This is the point at which plasticity replaces brittleness. These were our speculations, although of course, we did not know either the pressure at which plasticity would occur or whether it could be attained with existing experimental equipment.

Nevertheless, the inferred plasticity was discovered at the first attempt made in a high-pressure chamber designed for hydraulic extrusion. There, the sample is pressure-thrust through a narrow slot (the length of the extruded part of the sample suggests its plasticity under whatever pressure is in the chamber).

As a result, hydrogen-saturated titanium $(TiH_{0.1})$,[4] while absolutely brittle under normal conditions, under a pressure of $5.0\text{-}5.5 \cdot 10^3$ atmospheres seems to show signs of plastic deformation. With still higher pressure this effect grows exponentially, and at $10\text{-}12 \cdot 10^3$ atmospheres Ti starts flowing from the chamber in a wire as if it were molten. This extrusion happens at a temperature of about $100°C$ (the temperature in the high-pressure chamber during the experiment), whereas commonly titanium melts at $1\ 665°C$. In later experi-mentation, the effect of the marked increase in plasticity under pressure from hydrogen dissolved in the lattice has been proved for many other metals (iron, zirconium, niobium, vanadium, and others). The effect is probably universal for metals impregnated with hydrogen.[5] In addition to plasticity experiments, separate examinations were carried out to prove unambiguously that hydrogen-induced plasticity in metals is diffusive in nature.

It follows from these experiments that according to our model, the outer core of the Earth must be liquid (with dissolved hydrogen), while at the same time "cold." In later chapters we will show that the concept of a periodically-cold core does not present a paradox.

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[4] *With the composition of* $TiH_{0.1}$, *hydrogen is present exclusively in solution, a form in which it does not combine with metals.*

[5] *This phenomenon was used to license a technique for metal treatment by cold forging with prior saturation by hydrogen (author's certificate No 1165525, registered on March 1, 1985, with prior rights back to December 4, 1981)*

CHAPTER VI

TECTONIC CONSEQUENCES OF THE HYPOTHESIS OF A PRIMORDIALLY HYDRIDIC EARTH

6.1 An Expanding Earth

The cardinal tectonic consequence of the hypothesis of a primordially hydridic Earth is growth of volume. This growth is then repeated many times in the geological record, because of the consequential decompaction in the planetary interior from hydrogen degassing and hydride transformations of metals.

The hypothesis of the expanding Earth was advanced by O.C. Hilgenberg in 1934, when it became clear that continents have deep roots. Wegener's ideas of continental drift seemed improbable in this light. Hilgenberg's hypothesis was supported by many eminent scholars including L. Egyed, P. Jordan, and S.W. Carey. In Russia, active supporters included I.V. Kirillov and V.B. Neiman.

Recent data on the structure of the ocean floor, its sediments, magnetic field, regularly patterned median ridges, and the global rift system constitute a major advance in global geological theory. Tectonic and geophysical ocean-floor patterns demonstrate a gigantic construct of extension, whieh may be attributed to a general expansion of the planet (Heezen 1966). According to V.Ye. Khain (1970), the expanding Earth hypothesis may help resolve the long-term dispute between "fixists" and "mobilists" by attesting to structural permanence, the hallmark of fixism. Spreading between continental plates and the late creation of oceans are apparently correct concepts of the mobilists. Continents stay in one place, rigidly connected to deep-seated roots. But with planetary expansion they move apart, thus providing space for oceanic troughs to grow. M.V. Muratov (1975) took the position that the unfolding picture of the oceans "can be readily explained as topological development of the expanding Earth." More recently, these ideas have been actively promoted by Ye.Ye. Milanovsky (1978, 1983).

This hypothcsis, howevcr, is short of winning unanimous support among

geologists, because no realistic mechanism for expansion has been proposed.[1] The hypothesis of a primordially hydridic Earth relates the expansion of planetary volume to a specific, physically quite natural process. In this connection, the expanding Earth hypothesis needs to be discussed and analyzed at length.

Let us first consider current criticisms advanced against an expanding Earth.

(1) Some authors (Trapeznikov 1963; Belousov 1968) have taken positions that, had the Earth expanded through "swelling" of its interior, this would have led to the formation of archipelagos of tiny islands in place of modern continents, due to the pull-apart action in the process of swelling.

(2) If the oceans are to be considered structures of extension, why would expansion of the Earth have reached its highest level at the Paleozoic - Mesozoic transition and then continued through the Mesozoic so as to coincide with the emergence of the Atlantic, Indian, and Arctic oceans?

(3) According to some researchers (Kropotkin 1971), the Earth's expansion contradicts known facts of extreme horizontally compressive crustal shortening, which are established by direct observations. These compressions imply contraction of the modern planetary surface.

(4) Currently there is a widely held opinion that the expanding Earth theory falls short of accounting for folding, which requires horizontal compressive stress, and that it does not resolve problems of orogeny.

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[1] *Advocates of significant expansion of the Earth relate the phenomenon to mass incrementation through hypothetical nucleosynthesis in the bowels of the Earth. Atomic physicists object. Furthermore, the model fails in terms of pure mechanics, as our text will show. Admittedly, throughout geological history Earth's momentum has not decreased through the various available dissipative phenomena (tides, viscous friction, etc.); and the present "momentum" would, therefore, be characteristic of the planet throughout its history (mvR = constant). Thus, it is possible to calculate Earth's rotational velocity in past epochs. The calculation suggests that under conditions of significant reduction of Earth's radius and mass, its linear speed at the equator would exceed the escape velocity. Put differently, the body of the planet in the past must then have existed in a condition of rotational instability, with centrifugal forces higher than gravitational cohesive forces. Naturally, such a body would never have been formed, and should it have formed (by some miracle), it could not have survived.*

A way out of this reductio ad absurdum is possible only if we admit that the accumulated mass in the interior at the time of its birth had momentum equal to that of the present Earth. This proposition is precisely the case of one enigma explained by admitting another even more preposterous one. In this way one can explain anything at all.

Within the framework of the hypothesis of the primordially hydridic Earth, no problem of "rotational instability" ever existed.

Let us start with the first three arguments and leave problems of folding and orogeny to separate discussion. First, we will discuss the particulars of the expansion of the Earth, its hydrogen-bearing core shrinking and its mantle thickness increasing. We will in this way attempt to establish the pattern of planetary expansion in which swelling of the interior is not uniform everywhere but confined to one level, the core-mantle interface. This interface must then gradually migrate deeper into the planet.

To demonstrate this behavior, a very simple experiment was carried out. A small rubber ball was covered with a thin paraffin coating and inflated with air. The paraffin coating ("mantle") reacted to the swelling of the ball ("core") by producing a dense network of fine cracks, more or less evenly distributed all over the surface of the model ("globe"). But when the paraffin coating was thickened, the cracks grew coarser. Finally, when the thickness of the shell was 1/6th - 1/5th of the model's radius, the expansion produced a system of cracks that fractured the paraffin layer into several (six to eight) large plates, the shapes of which in some cases remarkably resembled the known continents.

By extending this experiment to the Earth, one may conclude that expansion with concomitant mantle thickening must take the same course. The fracture system becomes coarser, dimensions of extension structures on the planetary surface increase, and their numbers diminish. Let us examine whether this assumption conforms with geological evidence.

The primary evidence for extension structures on the planetary surface is recorded at the Archean-Proterozoic boundary (Pavlovskii 1975). At this time there was an emergence of a dense network of fine troughs (Glukhovskii 1976), or grooves (Markov 1962) which by the end of lower Proterozoic time had become transformed into a system of long belts, branching out and encircling relatively stable Archean core blocks only a few hundred kilometres across. A graphic depiction of Proterozoic belts on the Russian Platform was produced by Kalyaev (1965). Later, from Riphean time on, every new tectono-magmatic cycle produced an increment to the stable blocks, making them "platforms" in modern terminology. As this occurred, the intervening geosynclinal belts widened, and the resulting mega-fracture patterns became coarser, broader, and less intricate.

The topology of geosynclines that originated in lower Paleozoic time attests to the generalization that extension fractures up to that time followed major rift systems (the Urals, the Appalachians, etc.). Finally, during Mesozoic-Cenozoic times, extension was stabilized in a unified global system of rifts. This process led to dynamic growth of the oceans and to rift-associated mafic magmatism.

This scenario for the geological history of the Earth conforms to the results of our experiment, which purported to explain why the expanding planet had not produced archipelagos instead of the present-day continents, and why oceans tended to form in later stages of planetary evolution.

Expansion rates must also depend on the degree of compactibility of hydrides at all radial levels within the planet, although it is still unknown at

what depth; i.e., at what pressures, the compaction of hydrides reached the limit of proportionality (Figure 11). Had that happened at depths of one-fifth to one-quarter the radius of the primordial Earth, more than one-half the planet would have been composed of hydrides that were less dense than the inner planet. That would have triggered a quickly accelerating expansion, because the core-mantle interface would have moved deeper and deeper as hydrogen degassing proceeded.

Finally, the very mechanism responsible for the migration of the decompaction front may have intrinsic capacity for a "surprise" emergence of induced oceanic troughs. The sequence of geospheric shells representing Earth volumes in terms of radial positions implies that in the course of uniform (time-wise) expansion of the volume of the Mantle ($\partial V/\partial T$ = constant), a point "Z" would be reached at which its growth of thickness would accelerate (Figure 12). The foregoing experiment suggests that this should be accompanied by an abrupt concentration of extension structures into the major structures in this context, e.g., in oceans.
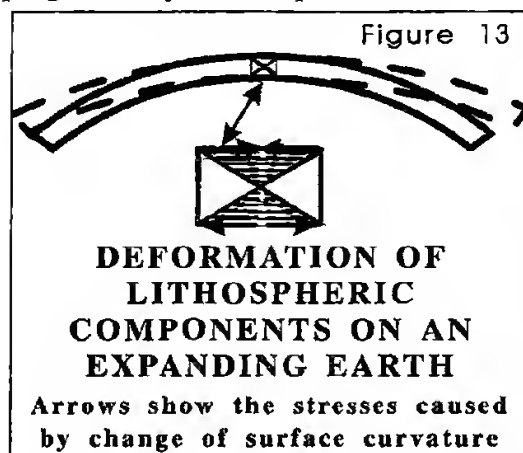

Figure 12

MANTLE THICKENING THROUGH GEOLOGICAL TIME
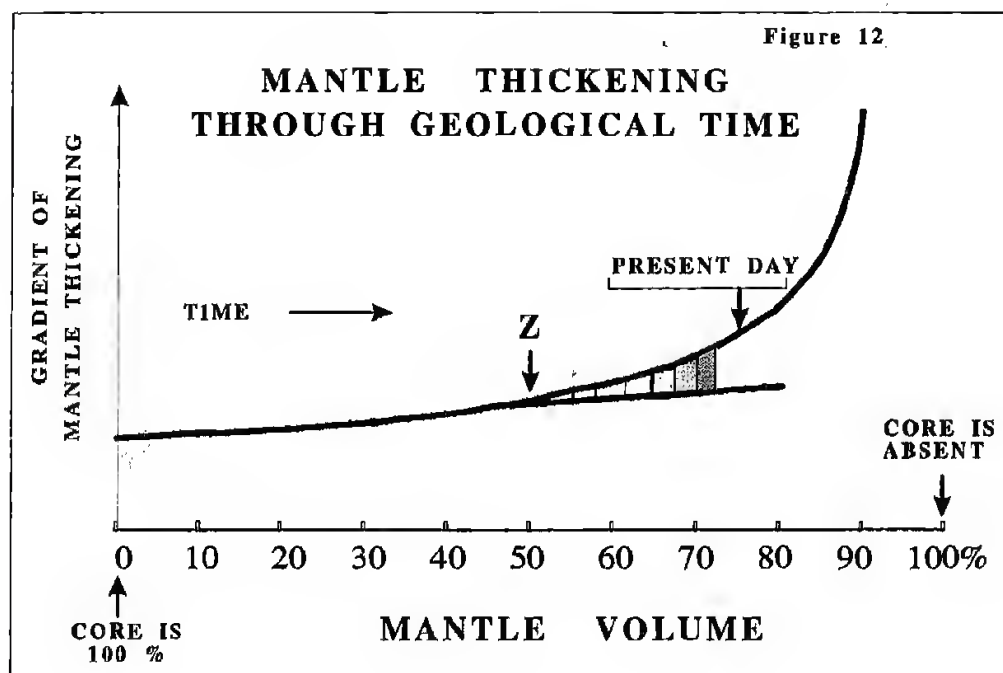
The volume of the present mantle is known. With the known densities of the core and mantle, it is easy to evaluate the volume of the terminal Earth, devoid of its core after complete hydrogen degassing. It is then possible to determine the present moment in the plot of Figure 12 and to examine the dynamics of mantle growth in terms of geochronology.

Thus, the hypothesis of the primordially hydridic Earth makes it possible to approach the intrinsic causes of ocean formation and the acceleration of the process during later stages of planetary evolution. A more detailed model of the ocean formation process is offered in Chapter VIII.

Let us now try to explain, from the precept of the expanding Earth,

how intense horizontal compression could occur in crystalline massifs where, according to numerous direct measurements, pressure may be 0.1 GPa at a depth of 1 km, or 3.0-3.5 times the lithostatic load (Hust & Nilson 1967)! For this purpose, we need to show the type of deformation that probably occurs in the course of expansion of the Earth in the supra-asthenospheric crustal layer. Initially deformation must be of extensional type so as to generate the fracture system that breaks up the supra-asthenospheric lithospheric layer into plates, which then float on the asthenosphere. Secondly, deformational flexing must occur, due to the growing radius of the Earth and the respective reduction of the curvature of supra-asthenospheric plates. Lastly, the plates straighten out, and the flexure distributes stress as shown in Figure 13: the uppermost layers are subjected to horizontal compression, which relaxes progressively with depth.

Figure 13

DEFORMATION OF LITHOSPHERIC COMPONENTS ON AN EXPANDING EARTH

Arrows show the stresses caused by change of surface curvature

Surficial and near-subsurface jointing and other porosity are responsible for stress relaxation at those levels. As a result, maximal horizontal compression of crystal-line massifs should be found at depths of 1.0-1.5 km, not near the Earth's surface, where subsurface lithostatic pressure seals most of the fractures.

Stress relaxation unexpectedly provides us with a possibility for testing whether the planet is really expanding now. If it is, the associated horizontal compression, below its maximum in the 1.0-1.5 km depth range, should decline. If this picture is true, there is hardly any other possible explanation but expansion of the planet along with accumulation of horizontal stress due to the reduced curvature of the supra-asthenospheric layer. Lateral pressure to depths of 2.5-3 km, caused by the redirection of elastic stress under vertical lithostatic load, can be neglected, as it is smaller by an order of magnitude than the horizontal compression with which we are concerned.

This assumption is presented in the form in which it was formulated by Larin (1971) and repeated (1975; 1980) in Russian variants on this book. However, when a book by Bulin (1973) summarized data on the stressed state of the Earth's crust to a depth of 2.5 km, it turned out that the redirected horizontal compression in the crystalline basement attains its maximum at a depth of about 800 m, and declines with greater depth.

Actual data, therefore, appear to prove our predictions. Redirected horizontal stress, if caused by expansion, must prevail in upper horizons of lithospheric plates from the reduction of their curvature. It must be a direct function of expansion of the planet, which causes it. Later in this book we will show in some detail that planetary expansion is most likely episodic and that the planetary interior has most likely cooled significantly with each

expansionary impulse. The cooling can effect thermal contraction of the planetary interior, and this would be expected to intensify the compression in the outer layer. Thus, the new model of the Earth unavoidably imputes compressive stress and the resultant strains to the crust.

6.2 The geosynclinal process: its cause and mechanics

The traditional point of view on tectono-magmatic activity, which has been forged by generations of geologists on the basis of scrupulous gathering of a huge data bank. Our model suggests and encourages a redirection of the search for the cause of geosynclinal development to the underlying mantle.

We have repeatedly suggested that the geosynclinal process is the result of a strong, mantle-produced flow of thermal energy into a narrow zone. Metamorphism, granitization, and magmatism of fold belts all indicate that geosynclines must have been zones of abnormally high heat-flow. Studies of the present thermal flux of our planet infer extreme heat emanation from zones of recent tectono-magmatic activity and young fold belts (Smirnov 1967a).

Heat emission at Earth's surface is regarded as evidence for a deep-seated source comprising the main source of energy for geological change on the planet (Smirnov 1967b). Thermal emission represents energy flux several orders of magnitude greater than the energy of volcanism, seismicity, or other heat-related processes. It is, therefore, sufficient to support various geological processes in the crust and upper mantle. However, no mechanism transforming thermal energy to tectonism has so far been devised.

Investigators in our day routinely resort to mantle convection to explain anomalous heat emission. Nothing else appears feasible, given the silicate composition of the entire planet down to its core. In our model there is no option to employ this concept because of the chemical boundary at 350 km depth. Even among researchers holding traditional views, there are many who reject mantle convection, some on the bases of its physics (Lyustrikh 1965; Knopoff 1972; Jeffereys 1970) and some its geotectonic applicability (Belousov 1966).

Any respectable geotectonic hypothesis must in the first place provide answers to the following questions. What are the reasons for extreme heat flows localized in comparatively narrow zones? What mechanism is responsible for heat energy transformation in tectonic geosynclinal scenarios with their regular patterns in space and time?

The problem of the geosyncline is so complex and the facts needing explanation so numerous that it must be modelled in a simplified manner with a restricted number of variables for any theoretical analysis to be feasible. Because the mode of planetary geodynamic activity has fundamentally evolved over time, this chapter is reserved to deal with the Phanerozoic geosynclinal mechanism. Figure 14 outlines the major occurrences of geosynclines and the stages in which they occur. According to the adherents to the A.V. Peive school of tectonics, the essence of these phenomena "...is the structural and compositional transformation of oceanic crust into continental

[crust]," during which the geosynclinal zone "...evolves through three major stages: oceanic, transitional, and continental" (Peive et al. 1976).

The oceanization stage timed to geosynclinal subsidence is characterized by extensive, initially-mafic magmatism (according to the H. Stille school of thought). It results mainly in deep-water sedimentary formations, which must have been deposited on an oceanic crust and be related closely to rocks of the melanocratic basement. The initial stages of the opening of geosynclinal troughs are in some cases (Ruzhentsev 1974) accompanied by specific "riftogenic" complexes: alkali volcanics (trachybasalts and trachyandesites) and coarse, mainly arkosic clastics. These are the products of erosion of the spreading continental blocks, and their emplacement implies that "...the geodynamic setting was mainly one of general extension" (Peive et al. 1976).

Already by the latter half of the oceanic stage the geosynclinal bottom was on the verge of being compartmentalized into elongate, geanticlinal rises separated by intrageosynclinal deeps. This phenomenon is manifested by the emergence of isolated geanticlinal structures (Kheraskov 1963; Volochkovich et al. 1972). Following that, the process of differentiation is compounded and has evolved to the transitional stage with its accumulation of thick flysch sequences and olistostromes that are viewed "... as indicators of strong thrusting under the tectonic pile-up" (Peive et al. 1976). Thus, the geodynamic setting at that stage featured compression in a general background of mostly-downward movements due to continued sedimentation. This is true at least during the time of flysch accumulation, when subsidence predominated..
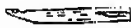
We must note that emergence of miogeosynclines takes place largely on continental crust, where normally there is no initial basaltic volcanism; i.e., no extensive opening of the rocks of the melanocratic basement. Hence, formally, the phenomenon is one of subsidence, and there is no ground for associating it with stretching. Furthermore, there is no reason to assume a regime of extension marked by the growth of geanticlinal swells (island-arc cordillera) in the next stage, with flysch series, wildflysch, and olistostromes. As a result, with the emergence of miogeosynclines or eugeosynclines at the later oceanic stage, geosynclinal sinking could hardly be a consequence of extension. In contrast, it must have been accompanied by crustal compression, as implied by evidence for tectonic imbrication. It is thus possible to accept to a certain degree the opinion that "...geosynclinal sinking and narrowing of structures are genetically related processes" (Kraus 1963). We have intentionally emphasized the contiguity of downward movements and a regime of compression at definite stages in geosynclinal history, because this phenomenon has eluded explanation up to now in terms of the expanding Earth theory.

Further history of geosynclines at the transition stage is marked by more intense tectonics, including imbricate piling-up and extensive thrusting climaxed by intense folding of accumulated sediments. Extreme thicknesses of deformed sequences, lead then into reverse tectonic movements.. Flysch troughs close at this stage, and sedimentation proceeds only at the peripheries of the geosynclines, where synchronously with the uplifting of the central portions that form a

fold belt, prominent foredeeps form and are filled with "basal" molasse (Trumpy's "molasse exogeosynclines"). Together with folding, regional metamorphism and granitization increase progressively in the folded sequences, with parallel "homodromal"[2] intrusions of granitoids distinguished by a geochemical predominance of sodium over potassium.

Figure 14

CRITICAL PHASE RELATIONSHIPS IN THE TECTONIC-MAGMATIC CYCLE

PROCESS	STAGES			
	I Geosyncline	II Inversion	III Orogenic	IV Post-orogenic
Downwarping and sedimentation				
Folding				
Metamorphism, granitization, magmatism, plutonism				
Mountain building				
Peneplanation, geomorphic evolution				

As was noted by J. Goguel (1969), "... if excess length of folded beds relative to their present width of occurrence could be explained by their earlier stretching, we would always be able to distinguish traces of such extension in thorough studies of rock textures; however, we do not observe this." Apparently, those who associate folding with vertical motions of the basement would be hard put to refute this objection. Most researchers tend to look for the causes of folding and thrusting in horizontal compression and reduction of the area originally occupied by sediments. This, however could have happened only with horizontal movements. Maximal folding stress occurs in the axial parts of geosynclinal belts; and diminishing levels towards the peripheries. The latter are characterized by box and brachyform folds (Sholpo 1964).

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[2] *Larin uses the term "homodrome," which is absent from English dictionaries, to mean "running parallel." Applied to plutons, the word means "aligned groupings."*

The present situation excludes application of compressive forces from outside, because plastic, still-unmetamorphosed sediments cannot transfer pressure over any significant distance. Yet these should be subject to maximal compression directly in front of the advancing foreland. In this connection, most researchers attribute folding and overthrusting entirely to compressional horizontal dynamics, which lead to reduction of the basal geosynclinal area that accommodates the sediments. Then, the lower crustal layers or even upper mantle horizons may prove active, whereas the less-dense granite-sedimentary layer is deformed according to movements of deep-seated matter (Mikhailov 1970; Ruzhentsev 1971). The causes of horizontal movements responsible for the narrowing of structures, as well as thrusting and folding, remain enigmatical.
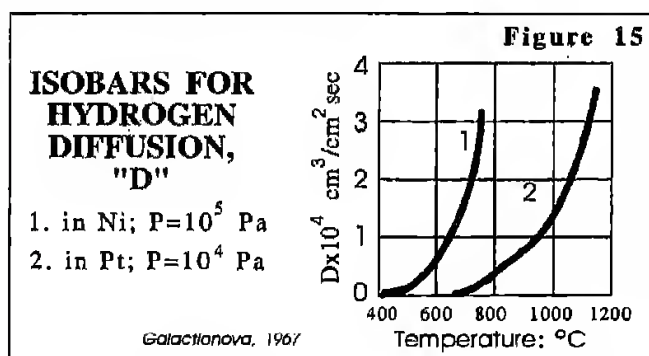
The continental stage that follows the transition is initiated by intense orogeny, which uplifts the entire geosynclinal area together with its foredeeps in a huge dome. Based on the timing of the "upper" molasse, our present stage is distinguished worldwide by a unique synchroneity of the tectono-magmatic activity cycle of geosynclines on the planet (Mossakovskii 1975). This synchroneity contrasts with antecedent folding. This kind of folding may vary in time from zone to zone in the stage of "general compression," (Mossakovskii 1969; Leonov & Mazarovich 1975). Domal arches show the highest levels of K-granitization and emergent granitoid batholiths in which K is petrochemically dominant over Na (Peive et al. 1976). In parallel with these processes, alaskite and subalkaline- to alkaline-granitoid plutons are emplaced, accompanied by orogenic volcanism.

Finally, the mechanism of the geosynclinal process at the orogenic stage should account somehow for the emergence of large intermontane depressions and seas over oceanic crust. According to Milanovskii (1969), "...contiguity of the phenomena of lithospheric extension and orogenic volcanism in intermountain areas, and compression in the adjoining fold belts may be related to a general deep-seated mechanism whose essence is not yet sufficiently clear." Peive (1967) suggested that "... some parts of the area of the Mediterranean, Tyrrhenian, Ionian, and Adriatic seas are newly formed and result from the extension of Alpine stresses." Recently, this hypothesis has been supported with the recovery from drilling the Mediterranean seafloor of late Miocene and Pliocene evaporites, indicating shallow-water, lagoon-type sedimentation. The present basin form and depth result from Pleistocene submergence contemporaneous with the adjacent Alpine, orogenic, doming.

Belousov cites facts suggesting that in middle Miocene time, the site of the present Mediterranean Sea was an upland from which huge amounts of sialic, terrigenous, clastic sediment was shed into the troughs to the north. In particular, the western slopes of the Apennine Mountains on the Tyrrhenian coast have been found to contain early- and middle-Miocene conglomerates with pebbles of metamorphic and granitic rocks brought there from the site of the present sea. That the structure of the river valleys of that time has been preserved amid their surrounding ridges is said to suggest that "... rivers flowed

then not to the Mediterranean Sea as they do now, but landwise away from the sea" (Belousov 1975). Some students of the subject have argued that tectonic reconstructions identify the area of the present Mediterranean Sea as the root sources of some nappe structures (Auboin 1977). It should be remembered that the neotectonic emergence of Mediterranean troughs went along with the "regeneration" of the crust from continental to suboceanic, as suggested by unconsolidated sediments, which occur there on the basaltic layer. Thus, to understand the mechanism of the geosynclinal process, the pattern of heat flux during tectonism is a central issue. Apart from the problematical energy source, understanding the heat pattern should illuminate recurrent phenomena in various tectono-magmatic cycles and show that they are not accidental and should be treated as parts of an orderly system.

The basic questions here involve the reason for geosynclinal subsidence, particularly at the stage when its development is parallel to the imbrication and the source of tectonic compression. Other questions are the causes of thrusting and folding that accompany the development of foredeeps. Why do metamorphism and granitization proceed after sedimentation at the inverse stage of fold belt histories? And, what causes simultaneous homodromal intrusions? What is the cause of synchronous, isolated arching of orogenic domes with concurrent subsidence of major, intermontane, suboceanic, crustal troughs and depressions during the closing stages of tectono-magmatic cycles? What brought about predominance of potassium over sodium in metasomatism and magmatism at the orogenic and post-orogenic stages? This is a list of questions, perhaps far from complete, which any geotectonic hypothesis should answer collectively.

Figure 15

ISOBARS FOR HYDROGEN DIFFUSION, "D"

1. in Ni; P=10^5 Pa
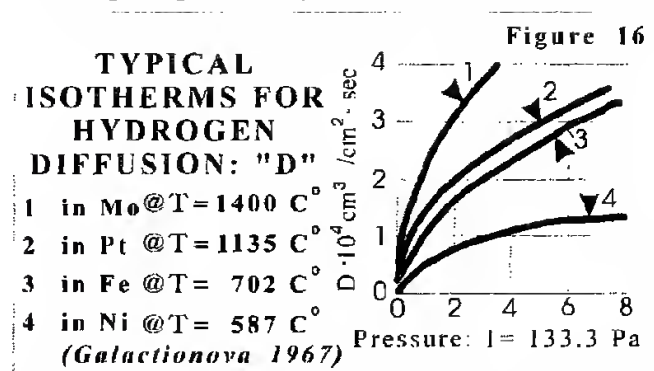2. in Pt; P=10^4 Pa

Galaclionova, 1967

The concept here proposed as the sole, intrinsic, and unique(!) cause for the entire gamut of the above phenomena is the degassing of hydrogen from the Earth's core.

For all the apparent complexity of the geosynclinal process, it may be entirely due to the systematics of hydrogen migration through the mantle toward its liberation at the surface of the planet. Hereinafter we show that the tectono-magmatic cyclicity in the geological evolution of the planet may be explained fully by an uneven, pulse-like delivery of hydrogen from the Earth's core. Each cycle of degassing is responsible for a complete cycle of tectono-magmatic activity. Importantly, stages of expansion of the planet and degassing cycles (in our hypothesis) must be spaced in time. The reason for this is discussed in due course.

However, before we look into the phenomena that accompany hydrogen degassing from the planet's deep interior, it is necessary to discuss the character

of hydrogen diffusion in metals and its potential for heat transfer.

The rate of hydrogen diffusion through metals is, in general, anomalously high (Folkel & Alefeld 1981). In vanadium at room temperature, the atom of hydrogen undergoes $2 \cdot 10^{12}$ jumps per second, a rate 15-20 orders of magnitude higher than the mobility of heavier, interstitial admixtures [such as oxygen and nitrogen] at the same temperature! At elevated temperatures, the rate of diffusion of hydrogen increases exponentially (Figure 15); and with higher pressure gradients, the diffusion rate also rises (Figure 16).

Figure 16

TYPICAL ISOTHERMS FOR HYDROGEN DIFFUSION: "D"

1 in Mo @ T = 1400 C°
2 in Pt @ T = 1135 C°
3 in Fe @ T = 702 C°
4 in Ni @ T = 587 C°
(Galactionova 1967)

Pressure: 1 = 133.3 Pa

The diffusion of gases and all elements in solids is a function of mobility and the creation of vacancies. The migra-tion of contaminating atoms may proceed selec-tively along micro-fractures or grain boun-daries as well as within lattices. (Friedel 1967; Collins 1992) Thus, the rate of diffusion in solids depends on the "graininess" of the solid sample, on strains within it, on the frequency of dislocations and on the energy with which vacancies are opened ("the vacancy activation energy").

Hydrogen diffusion rates in a variety of metals appear quite similar, however, and have nothing to do with the vacancies, sample graininess, or dislocations. These abnormalities are all due to that fact that hydrogen diffuses as a proton, owing to its extremely small dimensions [the reader will remember that it is five orders of magnitude smaller than metal atoms]. Its virtual point-concentration of charge and mass renders it able to penetrate not only the interstices of lattices (as some other elements do), but also in extra-crystalline fashion to penetrate electron shells (Galaktionova 1967). Apparently, quantum effects (tunnel passages) may also have some importance, because diffusion of hydrogen in metals can be observed at temperatures close to absolute zero (Folkel & Alefeld 1981).

It is interesting that the exceptional diffusibility of hydrogen leads to serious trouble in experimentation. The difficulty is caused by the capacity of hot hydrogen to flow, literally, through hot metal (a fact discovered by the author to his own dismay). The phenomenon is the high specific heat (absorptive capacity per unit of mass) characteristic of hydrogen. For molecular H_2 at 25°C, this figure is 14.4 J/g°K; for atomic H, it is 21 J/g°K, both orders of magnitude greater than other elemental specific heats. This behavior implies interesting applications for technology, where hydrogen is employed as a heat-transfer agent. Coupled with the capability of metals to occlude hundreds of times their own volume of hydrogen, this high specific heat can

be thought of as a high capacity for transmitting heat.[3]

The combination of exceptional heat capacity and remarkable diffusibility may prove to have many uses. High heat capacity makes hydrogen an effective heat-transfer agent and, perhaps, the mechanism for extreme heat flow through the mantle. The exponential dependency of hydrogen diffusion on temperature, wherein the diffusion rate rises steeply with higher temperature (see Figure 15), must result in the selective migration of hydrogen from hotter places. An originally-weak, selective flow of hydrogen protons, which may variously have been caused by thermal gradient fluctuation, variation in radioactive element concentration, or to an unrecognized reason, leads to additional heating along the path of hydrogen migration, because of the capacity of hydrogen to act as a heat-transfer agent. In turn, higher temperature boosts the hydrogen diffusion rate and creates a still hotter migration path and still more vigorous diffusion, and so on. It is easy to see that the ultimate result of this spontaneous process is an intense flow of heat concentrated along a narrow path.

Evidently, the origin of extreme heat flows cannot be resolved without the inferrence of efficient heat-transfer agents. The best candidate for this role (in fact, virtually the only one) is hydrogen through its heat-capacity and migration capabilities. There are numerous data today that attest to the predominance of hydrogen in fluids of the upper mantle (e.g., Marakushev & Perchuk 1972, 1973; Lutz 1975; Lutz et al. 1976; Letnikov 1976, 1977). These fluids are oxidized into water only in the crust, although not always even there, at least not completely (e.g., Betelev 1965; Vasil'ev et al. 1968). In this light, our geochemical model of the Earth works well, because it allows not only for abundant hydrogen but facilitates its escape in parallel coalesced channels from the deep interior of the planet. Even given the lowest estimates of hydrogen diffusion rates in metals, the time needed for it to travel from the core to the outer geospheres, through the metallic mantle, should not exceed 10^4 years. Had the entire mantle been composed of silicate and oxide minerals, the hydrogen would have been locked inside the planet, because its diffusion rate in silicates is several orders of magnitude below that in metals.

Let us consider the consequences of the extreme heat that originates with the selective release of proton gas. According to our model, the upper shells of the Earth comprise the Crust and an apparently-ultramafic, silicate-oxide, upper mantle. At a depth of 300-400 km, the "Golitsyn discontinuity," the silicate-oxide composition switches to a metallic composition (Figure 17). Within the silicon-oxygen shell there is a layer of low seismic velocity and viscosity, the "asthenosphere," or the "Gutenberg waveguide" (Magnitskii 1965; Gutenberg, 1963). Owing to its low shear strength, gradual asthenospheric distortion may lead to hydrostatic equilibrium in the tectonosphere, where it

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[3] *The hydrogen diffusion rate in iron at 800°C and a pressure gradient of 1 mm Hg/cm is about $1 \cdot 10^{-4}$ cm/sec. Hydrogen transfers heat at a rate of about $1.7 \cdot 10^{-4}$ W/cm², which is several times above the most extreme heat flux anywhere on the modern Earth.*

comprises the likely origin of isostasy. Beneath the continents, the asthenosphere ranges in depth from 100 to 250 km, while beneath the oceans it is much shallower, only 50-60 km (Magnitskii 1965). Additionally, it is to be noted that under the continents the asthenosphere may be discontinuous, lens-like. Commentary cogent to this subject follows:

(1) When heat is generated in layer C and the heat-conducting zone, a "tectonogene," in the terminology of Yu.M. Sheinmann,[4] is saturated with proton gas, the metals of the zone are compacted, densified, and rendered mobile (see Chapter V, section 3). As a result of the compaction, a throat[5] forms where the heat enters silicate shell B. This allows heat to enter shell B; and the compacted mass of hydridic material then sinks into the underlying metallic shell of the mantle (Figure 18a). To accommodate downward flowage in the throat, the asthenosphere reconfigures itself into a funnel-like depression. A logical consequence of this reconfiguration on the surface is the emergence of a geosynclinal basin with concomitant sedimentary infilling.

Figure 17

STRUCTURAL ELEMENTS FOR GEOSYNCLINE EVOLUTION
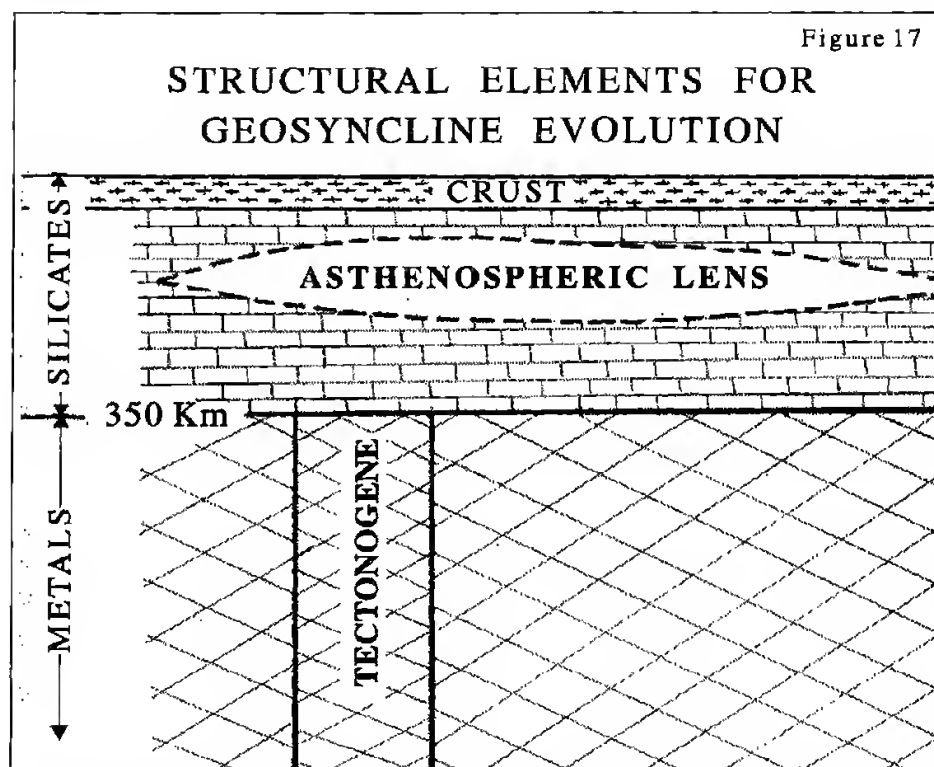
Then, if the tectonogene had entered a zone of rifting, and if oceans were formed coincident with the swelling of the Earth that was brought about by an intense pulse of hydrogen degassing, the structure would be eugeosynclinal,

[4] *Editor's note: The term "tectonogene," as used in this book means a crustal mass activated by hydrogen to produce tectonic structure.*

[5] *Editor's note: Literal translation gives "swallowing zone" here. "Throat" is used as a grammatical preference to mean not only a constricted orifice, but also to signify an orifice in which downflow occurs.*

thus, initiating ocean development. Had heat emanated independently of an extension structure, sediments would have accumulated on a continental crust, and the tectonogene would have led to the features of a miogeosyncline.
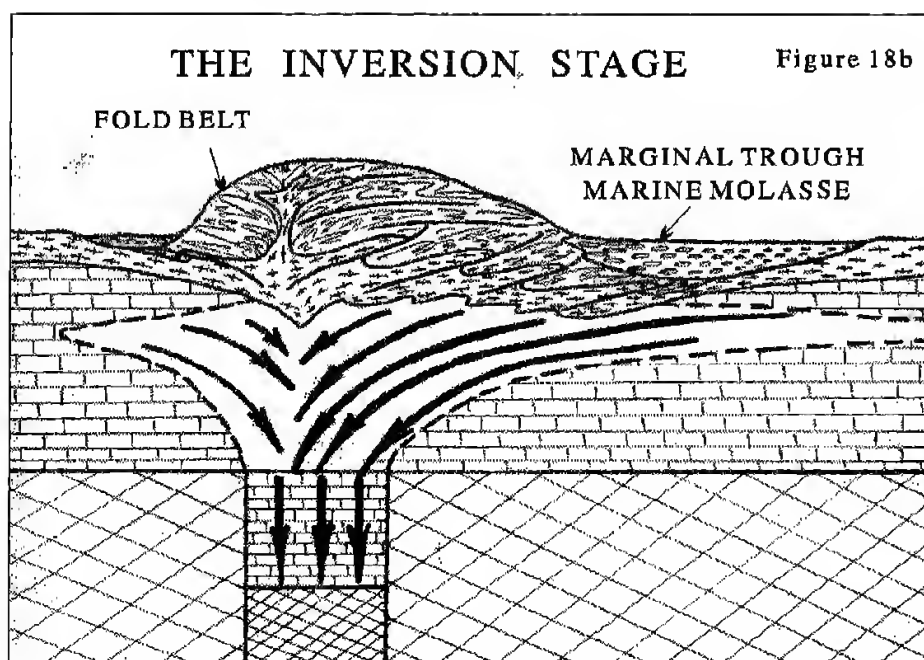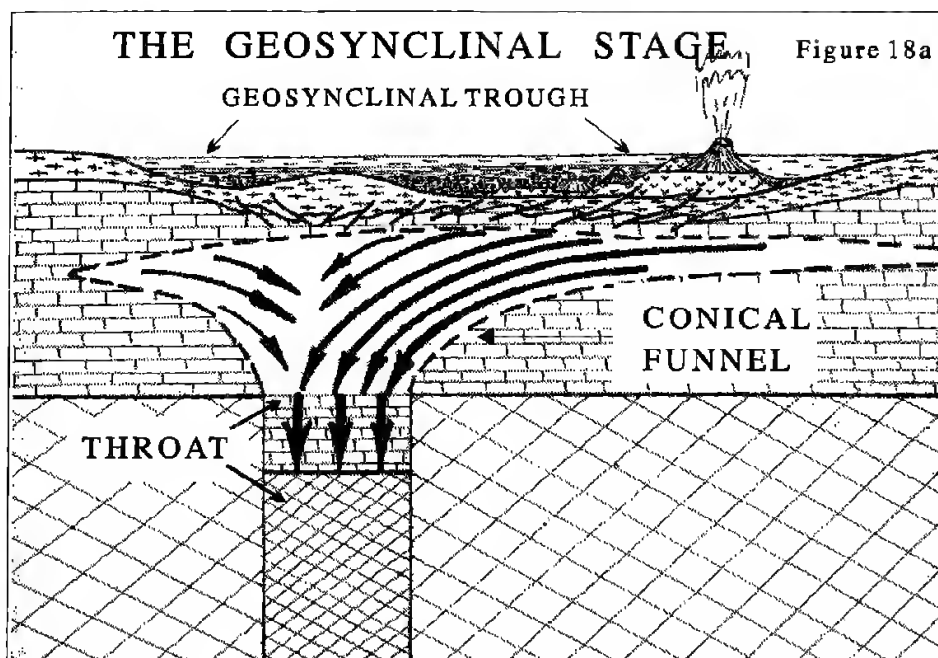
In figure 18 the arrows depict the direction of asthenospheric flow. This is in response to collapse of substructural support and despite friction between the moving asthenosphere and overlying crust.

THE OROGENIC STAGE

Figure 18c

CONTINENTAL MOLLASSE
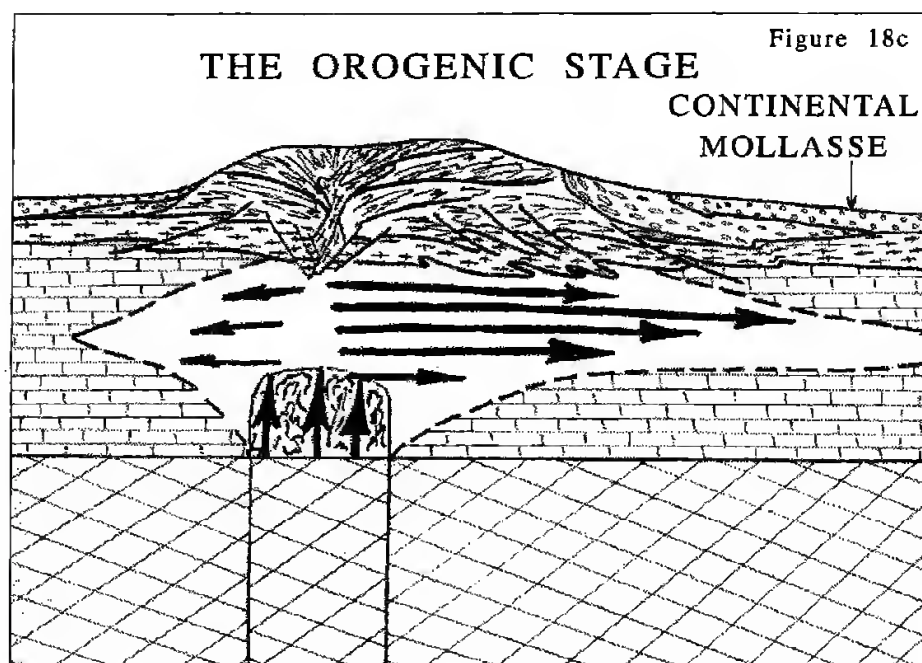
(2) As the throat deepens, the plastically deforming asthenosphere gradually fills in the funnel-like depression with material flowing nearly horizontally toward it from all directions (Figure 18b). Horizontal (tangential) stresses, transferred into the crust adjacent to the plastic flow of the asthenosphere, result in compaction as the geosynclinal center sinks. The regime of compaction in the inner geosynclinal zones produces thrusting, folding, and imbricate piling-up. The sequences being folded inevitably thicken. Tight folding may cause inversion of tectonic movement, interruption of sedimentation, and emergence of the upper boundary of the deformed sediments above sea level.

The compaction regime in the inner geosynclinal zones, because of the filling of the depression funnel, must be compensated by extension. Compensation takes place in marginal regions in the form of extrusion of asthenospheric matter. This mechanism perhaps explains the evolution of foredeeps (molasse exogeosynclines), the timing of which in our model must be synchronous with tectonic imbrication of the inner geosynclinal zones. Quite possibly, extension regimes on the peripheries of funnel-like depressions trigger the volcanic activity that occurs on the margins of geosynclines during their transition stages.

Plastic deformation and viscous flow in the asthenosphere inevitably lead to its heating and to dissipation of heat energy into overlying horizons. This is evidently the cause of regional metamorphism, granitization, and magmatism, which become manifest soon after a cycle of sedimentation. In this way intense orogeny is associated with maximal inflows into the asthenospheric funnel and, therefore, with maximal dispersion of heat into the Earth's crust.

Deserving of special attention in the light of our discourse, is the uneven rate at which tectonic imbrication occurs. Infilling of the depression

funnel is dependent on the viscosity of the asthenosphere; and the viscosity is dependent on temperature. Plastic flow is accompanied by asthenospheric heating and declining viscosity. Thereafter, increasingly dynamic movement in the asthenospheric funnel and concomitant imbrication in the geosyncline culminate in regional folding, which is completed within a brief span of time.

Regional variations in the original geothermal regime of the crust and mantle may be the cause of the differential timing of folding in different regions, which are later involved in the geosynclinal process. These variations are responsible for differences in the original viscosity of the asthenosphere. Lower original viscosity, for example, will energize a faster infilling of the funnel and an earlier start of folding. Vice versa, higher original viscosity at the waveguide may delay folding.

(3) Upon completion of hydrogen degassing of the Earth's core, the flow of proton gas in the tectonogene is terminated, and the tectonogene becomes vulnerable to decompaction. After the throat disappears, the depression funnel is transformed by arching of the asthenospheric. This is believed to be the root cause of the emergence of orogenic domes (see Figure 18c). Certainly, not only are fold belts involved in swelling, but their foredeeps are involved as well. Termination of active hydrogen degassing is a function of the exhaustion of the primordial hydridic core. This is a global event. As a result, any single cycle of orogeny should be virtually simultaneous in all geosynclinal regions, irrespective of their separation.

In the throat, through which and into which heat flows, any abrupt heating of the silicate material must be accompanied by the formation of water and other volatile compounds,[6] which inevitably lead to decompaction and reduced viscosity. As a result, silicate material rises from the throat as asthenoliths which, after they reach the surface of the asthenosphere, are dispersed by distension in the swell, where they become a source of heat and granitizing emanations that cause both magmatism and metasomatism at the orogenic stage. Apparently, asthenoliths can become buoyant only late in the inversion stage or at the stage of orogeny, when downward movements in the asthenospheric funnel have diminished (Figure 19a)

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[6] *Hydrogen in the throat must largely be expended in various chemical reactions that yield volatile hydride compounds. Alternatively, it may provide a proton fill to broken links of oxygen bonds in the silicate groundmass, acting as a depolymerizer and bringing down viscosity. Further migration of hydrogen and its derivatives through the silicate-oxide shell must be related to processes of diapirism.*

THE EVOLUTION OF A FOLD
BELT IN THE OROGENIC STAGE

Figure 19a

ASTHENOLITH

Figure 19b

Figure 19c
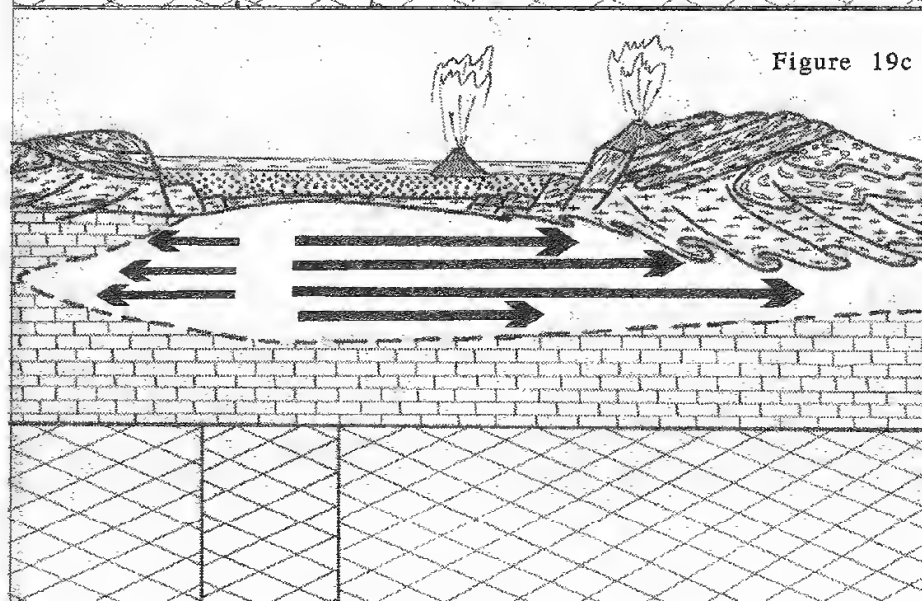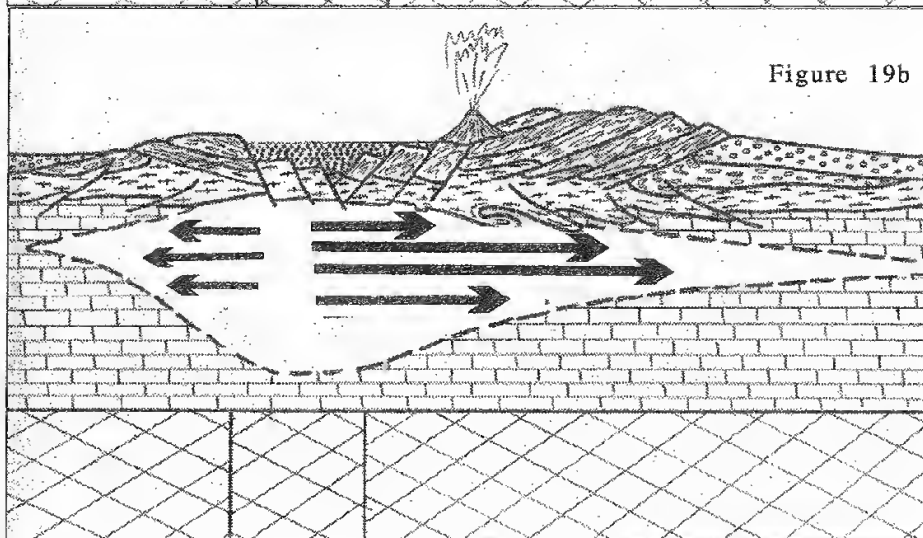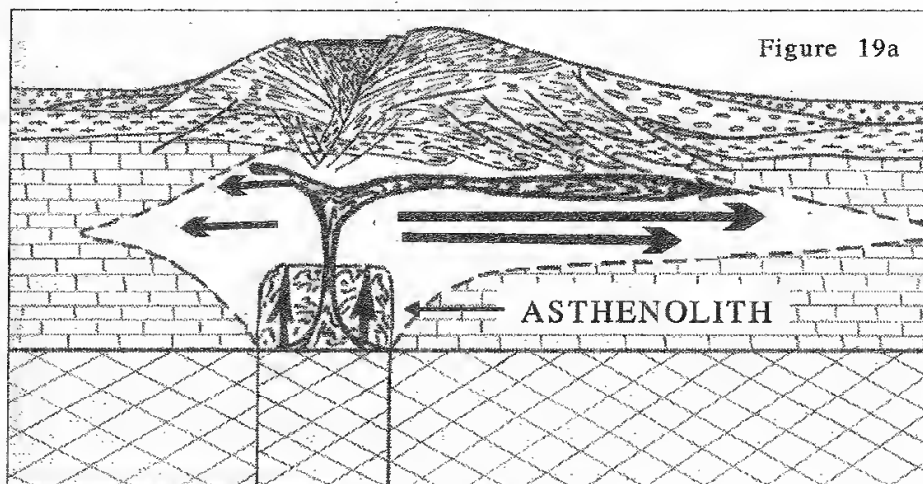
A) Uplift of the orogenic arch and its erosion. "Relief" is relocated to "upper level" molasse.

B, C) Subsequent stages in which the orogenic arch is stretched by a spreading plume of asthenosphere below a domed surface. This leads to intermontane valley subsidence and folding of previously deposited molasse sequences.

Increasingly, involvement of potassium in the processes of metasomatism and magmatism at the orogenic stage may be brought about by hot, deep-mantle substances, which enter subcrustal horizons from the lower levels of the silicate-oxide shell with the upwelling asthenoliths from the point of entry of the tectonogene. The reason for the entry of such substances is that higher concentrations of potassium and other less dense, lithophilic elements are present in lower levels of the silicate-oxide shell by comparison with the upper mantle zones directly beneath the crust. This phenomenon is separately discussed at length below.

We shall now consider patterns of the geodynamic regime in the crust and mantle at the orogenic stage. Whereas at the transition stage, the infilling of the mantle depression funnel led to the tectonic imbrication of geosynclinal sequences and the regime of compression within fold belts compensated by extension in foredeeps, the emergence of the asthenospheric swell at the orogenic stage must generate the opposite geodynamics and distribution of stress. As above noted, whereas asthenospheric swelling produces orogeny, the swell, by virtue of isostasy, is bound to distend and, thus, to provide for extension of the orogenic dome in the directions of predominant distension. This extension is compensated by compression in terrains that adjoin the forelands. Presumably, it must be characteristic of tectonic structures of extension that they be dominated largely by the topography of asthenospheric arching (the higher the swell, the broader the distension).

A jet-like mode of flow in the tectonogene must result from the exponential dependence of hydrogen diffusion rates on temperature. Uneven atomic compaction along the strike of the heat-conducting zone and disparate depths to the throat are responsible for the subsequent topography of the asthenospheric swell. The swell must be amplified by domes above the deepest throats, because it is there that maximal hydrogen flux occurs. Inasmuch as the deepest throats are also the hottest, they must produce the most asthenoliths, which rise during the orogenic stage and amplify the domes of the asthenospheric swell with hot abyssal matter from the lower levels of the silicate-oxide shell.

It is precisely these domes and their distensions atop the asthenospheric swells that the new model associates with emergence at the orogenic stage of intermontane troughs of the Hungarian type (Figure 19b). This model also accounts for their specific features, such as thinning of the crust, elevated heat flow, convergence of the asthenosphere with the Earth's surface, and volcanism. All of these are features for which extension has facilitated magmatic upwelling and rupture of the lithosphere.

Finally, an extreme case of extension is the Mediterranean-type of interior sea (Figure 19c). Crust of the suboceanic type in young formations must originate not only by distension of asthenospheric domes but, even more prominently, by deep erosion of the granitic layer of the crust during the initial stages of orogenic doming, at which time great oval domes arise and later relax and sag. At their maximum developments, the domes are areally the highest of topographic features (Figure 19a). As a figure of speech, the Mediterranean-type troughs are gashes in the crust, to which erosion contributes sediment through endogenic and exogenic processes.

Whereas the viscosity of the waveguide around the asthenospheric dome may vary widely, its distension may be asymmetrical or even unidirectional. It is then understandable that neotectonic troughs in plan have diverse shapes. Clearly, this mechanism allows for the existence of arcuate mountain chains rimming intermontane troughs and their seas. These are interpreted as remnants of originally-single orogenic domes. On the opening of a trough, the plan of the surrounding mountain arcs must change, their steepness increasing in the direction of the dominant distension of the asthenospheric swell. Occasionally, such mountains "override" their respective foredeeps, causing deformation and folding of the sedimentary infill.

Thus, intermontane troughs and "Mediterranean" seas are believed to be regular elements of the orogenic stage. Although typical of the Alpine cycle, they may have become reduced or eliminated altogether from earlier tectono-magmatic cycles. We shall try to explain this in the discussion of the evolution of geodynamic regimes through time.

(4) In the post-orogenic phase of the continental stage, progressive cooling of the lower crustal horizons and uppermost mantle may lead, in a platform-like setting, to the emergence of brachyform troughs, which sink slowly over long periods, due to phase transitions of the basalt-eclogite type. Concomitant rising of the Mohorovicic discontinuity is considered possible on platforms (Magnitskii 1965). The nature of such a trough is, of course, quite different from the features that characteristize the opening and evolution of orogenic-stage intermontane troughs.

Manifestly, the geosynclinal development mechanism deduced from the hypothesis of the primordially hydridic Earth, easily provides answers to many of the questions that are posed above. It accounts for (1) the paradoxical implication of a connection between geosynclinal subsidence and extreme heat emission, and (2) the paradox of the interrelationship between mountain building and heat dissipation. Looking from the viewpoint of the new theory, it explains why tectonogenic mass is compacted as it is heated, and why it expands when cooled. The author can find no solution to these paradoxes outside the framework of the proposed geochemical planetary model in which periodic degassing of inner geospheres involves hydrogen jets that carry and expell heat in enormous quantities to outer geospheres. This process leads to the compaction in tectonogenes saturated with proton gas and to their ensuing decompaction following the end of the degassing cycle.

Let us discuss some auxiliary consequences of the proposed mechanism for geosyncline evolution and draw parallels with the known geological facts and existing points of view.

The deep-seated origins and geosynclinal development that follow from the hypothesis suggest a separate oceanic stage for the evolution of eugeosynclines. This stage is manifest when a tectonogene originates with an oceanic structure of extension that (1) appears to regenerate into a geosyncline, (2) is later exposed to imbrication, and (3) undergoes orogeny. Such regeneration continues to be possible only up to a certain point in ocean opening. This limitation is explained in Chapter VIII, under the discussion of ocean formation, as one of the implications of the hypothesis of the primordially hydridic Earth (see Chapter VIII).

Interestingly, as early as 1906 Ampferer described the throat (or "swallowing" zone) as situated "somewhere below." The idea seemed promising as an explanation for orogens with regional, and bilateral nappe structures, which have been attributed to the autochthon underthrusting the allochthon and hence to bilateral (forward as well as reverse) folding. But since ingurgitation appeared impossible in the absence of void space within the Earth, it was suggested that folding was the result of crust being drawn downward by convective flow (e.g., Kraus 1963;). This concept, however, contradicts the entire panoply of phenomena that accompany geosynclinal folding, especially regional metamorphism and granitization, which imply elevated heat gradients (Belousov 1963). Elevated heat efflux can hardly characterize the downward-flowing member of a thermally-generated convection cell. The new theory supports the earlier idea of Ampferer on the cause of folding by allowing for the formation of throats and ingurgitation.

For some reason, researchers tend to ignore the twofold nature of the growth of fold belts. One member is the "lower" (mostly marine) molasse; the second is the "upper" (continental) molasse. In some cases these are quite widely spaced in time. The first uplift of the Alps, for example, took place in the Upper Cretaceous - Paleogene time, together with the principal thrusting, folding, and rock metamorphism. It was accompanied by the emergence of foredeeps, which eventually were filled by the lower molasse. Already by the start of Pliocene time, however, erosion had destroyed the mountains, and the fold belt was but a hilly peneplain. The modern Alps are the result of the second uplift event, Pliocene - Pleistocene in this case, which also involved foredeeps. Clearly, the geosynclinal mechanism must allow for the dual events of uplifting of fold belts (whether or not existing hypotheses prefer to ignore the fact). In our model, the first uplift logically ties in with the apogee of tectonic imbrication and the growing thickness of deformed sequences. It is consequential upon the infilling of the depression funnel in the asthenosphere (Figure 18b). Subsequent uplifting is brought on by the decompacting of the tectonogene (Figure 18c).

The proposed hypothesis brings us closer to comprehending the intrinsic nature of recurrent, cyclic, intrusive events. Beginning with early ultramafics

and gabbro-plagiogranites; subsequent intrusive processes develop from gabbroids and gabbrodiorites to diorites and granodiorites to normal biotite granites, culminating (at the orogenic and post-orogenic stages) in the emplacement of intrusions of alaskite and subalkalic-alkalic granites (Beskin & Marin 1972). What is not clear is the emplacement in abundance of alaskite intrusions and alkalic granites that are rich in water and volatiles at the orogenic and post-orogenic stages, that is, after the stage of metamorphism, when the crustal level of granite formation should have been virtually water-free.

According to the new hypothesis, early ultramafic rocks and gabbro-plagiogranites and the initiation of volcanism as well, can be attributed to the extension of oceanic terrain at the stage of Earth expansion that preceded the extreme heat emissions from hydrogen degassing of the planetary core. With the origination of the throat and funnel-like depression, heat dissipation from the asthenosphere led to the rise of the geoisothermal gradient as a gradually advancing front of metamorphism and magma generation through the basaltic, dioritic, and granitic crustal levels. This sequence may correlate with the generative process that leads to the gabbro - diorite - granodiorite - granite series of syn-folding intrusions. The latter naturally occur only in their proper geosynclinal zones, depending on the magnitude of heat generation in the depression funnel.

Alaskites and alkalic granites at the orogenic and post-orogenic stages of the regressive phase of metamorphism correlate with the regime of rising asthenoliths, which transport heat, hydrogen, water, other juvenile components, and [apparently] the metals that are needed for granites, from the throat to subcrustal levels. This provenance permits understanding of such general maxims as: (1) the youthfulness of the metallogeny of alaskite and alkalic intrusions, (2) their presumed saturation with volatile components, and (3) the possibility for their development outside their proper geosynclinal habitats. Rising asthenoliths would be blocked as the horizontally-spreading asthenosphere became disconnected from the throat, which had disappeared (Figure 19a).

The proposed theory leads to discussion of the causes of epiplatformal mountain-building. For example, the Ural and Tien Shan mountains rose by Neogene - Quaternary uplift of terranes which in Mesozoic time were preserved by geosynclinal subsidence. Hence, the conclusion that mountain building can proceed without any connection with a tectonogene, is to say that the real mechanism is quite different, one not previously envisaged in theory. In fact, the proposed mechanism of mountain-building does demand a connection with a preceding cycle of subsidence. The process, however, may be distinctly variable. It depends on the vigor of hydrogen flux, which in turn is a response to the level of activity of the tectonogene, and to the structural and tectonic conditions under which hydrogen escapes from the deep interior and penetrates the silicate-oxide shell.

Belts of epiplatform orogeny may have a higher geothermal gradient

than shields and platforms but still less than the Alpine fold belt (Belousov 1975). All recent gauging of terrestrial heat flux indicates gradients consistent with the dissipation of residual heat. This suggests that at the time of regional metamorphism gradients must have been many times steeper. Since regions of epiplatform mountain-building were not exposed in Tertiary time to the metamorphism typical of Alpine folding, it can be assumed that the late Tertiary heat flow has been several times less than in Alpine times. Consequently, the later tectonogenes must have been essentially less saturated with hydrogen. A lesser hydrogen flow must have reduced the tendency to subside at the entrance of the tectonogene, and curtailed the development of the funnel-like depression. Concurrently, at the surface, instead of a vast geosynclinal trough, there would have been only shallow depressions with thin and locally-derived sedimentary fills, and minor magmatic plutonism.

Starting in Triassic time, when tectonism reactivated the Urals and Tien Shan terrains, movements were characterised by numerous graben-type troughs in which sedimentation (including marine sedimentation) shadowed by active volcanism proceeded through Cretaceous time. In the Chelyabinsk graben, for example, the sedimentary column is up to 2.5-3.0 km in thickness, and the sediments are disturbed only by faults and simple folds. In the Tien Shan, there were occasional geosynclinal troughs which accommodated kilometres of Mesozoic sequences exposed to moderately intense folding (e.g., Fergana Ridge). Recent data suggest comparatively widespread Meso-Cenozoic intrusive magmatism and metallization in the Tien Shan Mountains (Mushkin 1973).[7]

These data support the interpretation of epiplatform mountain-building in the framework of the proposed hypothesis. It is seen as the result of an incomplete tectono-magmatic cycle, because its geothermal gradient is less than Alpine gradients. Epiplatformal orogenic uplift of this kind may be due either to less tectonogenic action or to heating of the subcrust and the attendant growth of mountain roots by the conversion of eclogite to basalt. Incrementation of a mountain root is consistent with known thickening of the basaltic layer below epiplatformal orogens.

It may be useful to consider the consequences of tectogene evolution into monoliths within the silicate-oxide shell, where the asthenosphere is either absent or poorly developed. Such monolithic blocks comprise the ancient platforms and ancient folded terranes, which have remained tectonically at rest for a long time. In the light of our hypothesis, the absence of the asthenosphere leads to a highly specific tectono-magmatic scenario. First, instead of a broad geosynclinal basin, one should expect formation of a narrow trough similar to a graben, or to a down-faulted syncline filled with molasse-type sediments. Second, because no asthenospheric funnel-like depression forms, folding is missing or weakly developed, and block faulting

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[7] *In a related situation, the Eurasian Hercynides exhibit mainly individual troughs, implying a geosynclinal regime that could have been revived early in Mesozoic times (Shlezinger 1971).*

predominates. Third, there is no metamorphism of the sedimentary fill, and fourth, there are no emplacements and concurrently-folded homodromal series of granitoids. Plutons are largely K-rich, mantle derivatives, a petrological property of platform magmatism that is discussed further in Chapter VII.

It readily follows that the above specifics of tectono-magmatism conform completely with the typical patterns of mobile belts on platforms. These phenomena may, therefore, be attributed to the impoverished "quality" of the asthenosphere; whereas geosynclinal fold belts, epiplatform orogeny, and tectonic activity may be interpreted as having a single provenance: *hydrogen degassing of the planetary interior*. Diversity of tectono-magmatic activity is due to diversity in rates of hydrogen emission into the tectogene and the "quality" of the asthenosphere.

Let us now look at zones of modern tectono-magmatic activity. Many researchers regard paired deep-water trench and island-arc features and the marginal seas they delimit (e.g., Sea of Japan, Okhotsk Sea) as examples of modern geosynclines. Their positions on the peripheries of continents suggest growth of continents at the expense of oceans. An alternative view correlates such structures with "oceanization" of continents. These paired structures are everywhere similar, their convexity facing oceanward. Starting at the trench, the seismically active zone, known in the literature as the Zavaritsky - Benioff zone, dips under the continent, extending as far down as 600-700 km (Figure 20).

Data on the spatial distribution of earthquake foci, type of stress, and the magnitude of seismic energy release all imply a viscous flow of the asthenosphere beneath island arcs and their marginal "backarc" basins (Isaev 1969). High heat flow in marginal seas and on island arcs is attributed to heating of the asthenosphere by the viscous flow. Geophysical data suggest a shearing type of deformation at shallow- and medium-depth seismic foci. The nature of motion at deep foci is moot. One suggestion is that it may be due to volume changes, that is to say, compaction and decompaction of mantle substances (Verhoogen et al. 1974; Sheinmann 1968). Special attention is deserved for the bend in the dip of the loci of foci, a feature typical of the Zavaritsky - Benioff zone at a depth of about 300 km. This bend must not be neglected in any attempt to explain the mechanism of tectono-magmatic phenomena in transition zones.
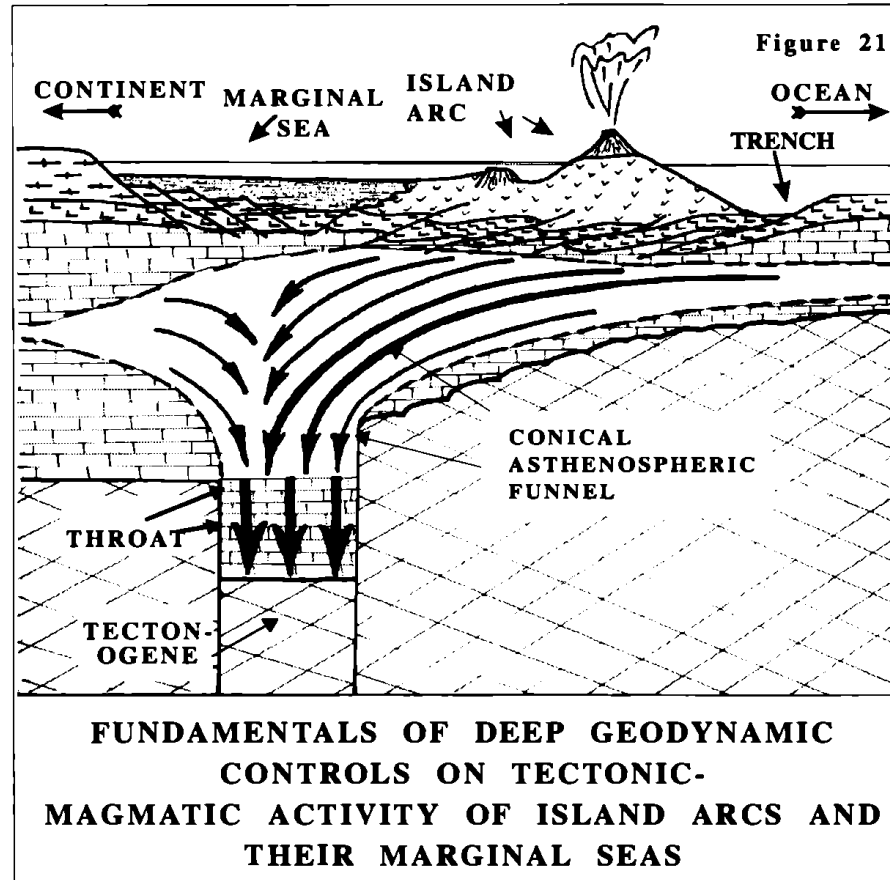
THE KURIL-KAMCHATKA ARC

Figure 20
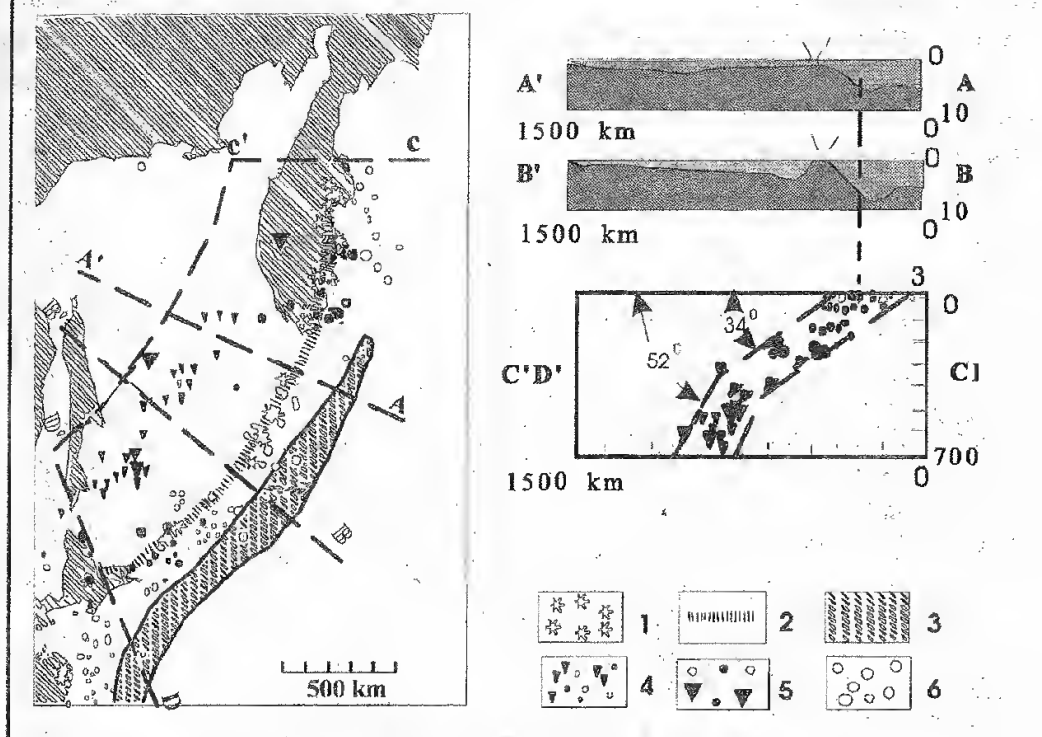
1) Volcano; 2) the volcano line; 3) oceanic trench;
4) earthquake of magnitude 6.0 - 6.9;
5) earthquake of magnitude 7.0 - 7.75;
6) earthquake of magnitude 7.75 - 8.5.

- after Heezen (1966)

In terms of our hypothesis, deep-focus seismicity must be associated with the entrance of the tectonogene, where the mantle likely exhibits a variable content of intermetallic compounds because of its saturation with hydrogen protons. Throat formation above the region of deep-focus seismicity is implied by specific patterns in the geomagnetic anomaly of Japan, which, according to Rikitake (1968), is due to deep penetration of the upper (non-conductive) layer B, which wedges into the electrically conductive (metallic, in our interpretation) mantle. The evidence for this wedging is inherent in the specific seismic patterns of the deep foci. For example, in an earthquake at a depth of 600 km in Peru, seismic strain guages recorded at the epicenter a downward dislocation relative to the Earth's surface (Verhoogen et al. 1974).

Medium-depth seismicity logically correlates with infilling of the asthenospheric funnel-like depression, which is manifest at the surface in the form of the geosynclinal basin of a marginal sea. This interpretation (Fig. 21) accounts for the dip change in the plane of earthquake foci. Deep-water trenches and island volcanism must be due to the extreme distension of the oceanic crust and its rupture at the edge of the funnel-like depression, which

is at the stage of being infilled. The oceanward position of island arcs and trenches may reflect an oceanward inclination of the funnel-like depression and lessening of its effusion under the continent. The island arcs must be produced by hotter, less viscous, and more highly mobile mantle beneath the ocean.[8] Shallower depths to the asthenosphere and attendant thinning from the continent oceanward of layer B in the transition zone may to some extent correlate with the regular decline towards the continent of the zone of medium-focus seismicity in the asthenosphere.

Figure 21

CONTINENT MARGINAL ISLAND OCEAN
          SEA   ARC

TRENCH

CONICAL
ASTHENOSPHERIC
FUNNEL

THROAT

TECTON-
OGENE

FUNDAMENTALS OF DEEP GEODYNAMIC CONTROLS ON TECTONIC-MAGMATIC ACTIVITY OF ISLAND ARCS AND THEIR MARGINAL SEAS

This interpretation does not preclude the existence of submerged, little-altered blocks of continent beneath the terranes defined as island arcs (Bogdanov 1965). The "oceanization" of such blocks is unlikely to occur, because the

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[8] *Heat emission from continents is approximately equal to that from ocean floors, whereas the oceanic crust and mantle appear to be better heated than their continental counterparts. It must be noted, however, that the generation of heat in the upper part of the continental crust to a depth of 35 km comprises two thirds of the emission at the surface, while in oceanic regions only 10 percent of heat is generated within the same depth range (Lyubimova 1970).*

mechanisms proposed to accomplish it do not allow for any general replacement by mafic magma during the stage of infilling of the funnel-like depression and crustal compression. An exception occurs at the periphery of the depression funnel, where the continuity of the crust is breached and extension is dominant. However, in this case island volcanism is more likely to lead to the formation of new continental crust at the expense of oceanic crust.

Plate tectonic theory makes use of the Zavaritsky-Benioff zone to illustrate two cardinally opposing constructs. First it holds that subduction in deep-water trenches forces oceanic lithospheric plates that grow by spreading from mid-ocean rifts. Then it holds that they are either driven or sink gravitationally into the planet along the dipping plane of earthquake focal centers. In terms of our hypothesis, there is no subduction of oceanic crust. The Zavaritsky-Benioff zone is attributed to the working of the tectonogene with its conjugate funnel-like depression in the asthenosphere.

To validate this conjecture, let us turn to the structure of trenches. In our hypothesis, trenches result from extension tectonics over the curved periphery of the funnel-like depression (Figure 21). This contrasts with the plate tectonic hypothesis, which requires tectonic compression along a collision front between oceanic lithosphere and an island arc or a continent.

Deep-water trenches are 50-100 km-broad grabens produced by stepwise normal faults or to a combination of faulting and flexing. Structures on this plan are only possible by extension. Extension forces are also necessary to account for the crustal thinning that occurs on the oceanward margins of island arcs and continents. Under conditions of compression, crustal thinning would be improbable. *"It thus can be concluded that in the region where a trench formed, forces of extension were at work"* (Worzel 1970). Worzel's deduction denies plate tectonic theory and favors the interpretation that follows from the primordially hydridic Earth theory.

The foregoing evidence may be supplemented by considering some other problems which appear too difficult for plate tectonics to handle. Why do unconsolidated sediments only accumulate sparsely in trenches? How do we explain the aseismicity of the ocean distant from island arcs and trenches, given the imagined vigorous movement of the plates over the entire ocean floor? What explains the difference between coasts of the Atlantic and Pacific types? How does one correlate spreading and subduction on a global scale, given that regions of crust generation, median ridges and continental rifts are several times more extensive than the Zavaritsky-Benioff zones, which among themselves do not even constitute a unified or continuous system?

In some places, correlation between the plan of a trench and the configuration of its complementary zone of deep-focus seismicity may be unique and recalcitrant to interpretation as subduction of the oceanic lithosphere. The mismatch is what we find at the Tonga Trench (Figure 22), among other places. Remarkably, the trench overlies a prominent center of deep-focus earthquakes, a topology that suggests a causal relationship. First we must

define the constraints on the site. A plate tectonic interpretation on this site requires the subducting oceanic lithosphere to be bowed and inclined almost to vertical in order to be thrust to a depth of more than 600 km. Through all this it must [inexplicably] retain its internal contiguity. Furthermore, as the temperature regime in the sub-oceanic mantle at depths of less than 100 km, should already have rendered the mantle rock plastic (incipient asthenosphere), the preservation of contiguity to depths of several hundreds of kilometres is absurd. On the other hand, if we treat the zone of deep-focus seismicity as a throat, its configuration then conforms to the trench bordering the funnel-like depression. The topological coincidence of trench and earthquake focal points is now unsurprising, and rather,.is undeniably supportive of the new hypothesis.

A diagnostic condition for seismic prognosis based on plate tectonic assumptions is the situation where "... strong earthquakes are to be expected in those segments of seismic belts where there have been no strong earthquakes for decades or centuries" (Sykes 1975). This deduction is derived from the conjecture that a belt of seismicity is a demonstration of active plate subduction. Because subduction can hardly be local, it is expected to involve the plate all along the subduction front. Gaps in the seismicity pattern imply a delay in stress relaxation. Stress, therefore, is thought to accumulate in the form of elastic deformation, which inevitably at some future time must be released and cause an earthquake.

Our perception, on the other hand, is that jet-like flows of hydrogen inevitably must be discontinuous along belts of active seismicity. This should be especially true of deep-focus activity, because of compaction and densification of the components of tectonogenes as they are affected by ambient hydrogen. Zones of medium- and shallow-focus seismicity, which are caused by the infilling of the asthenospheric funnels, are much broader, and can merge into a unified belt, which would inevitably have gaps where neighboring depression funnels had failed to coalesce. However, our model predicts no incipient seismic hazards within the gaps, either today or in future.

Thus, in contrast to plate tectonics, the hypothesis of the primordially hydridic Earth requires no rigid structural relationship between spreading and Zavaritsky-Benioff zones. Although both of these result from hydrogen degassing of the inner geospheres, the zones are self-regulating and independent of one another. Their preferential positioning on the continent-ocean margin defines a discontinuity in the mantle that penetrates far into the planetary interior (Figure 47). The existence of a continental margin discontinuity is, in fact, supported in geophysics (Toksoz & Anderson 1966). By dividing the mantle into suboceanic and subcontinental blocks, the discontinuity comprises a network of important paths for the migration of hydrogen from the Earth's core. Where it conducts a strong flow of hydrogen, the conjunction between continent and ocean, involving marginal seas and island arcs, is said to be of Pacific type. Lacking a strong hydrogen flow, the coast is described as Atlantic type.

THE TONGA TRENCH

Earthquakes with Hypocenters Deeper than 600 km
after Sykes (1970

Figure 22

DEPTHS

▽ 500 - 600 KM

+ > 600 KM

▨ OCEAN DEPTH > 6 Km

V VOLCANO
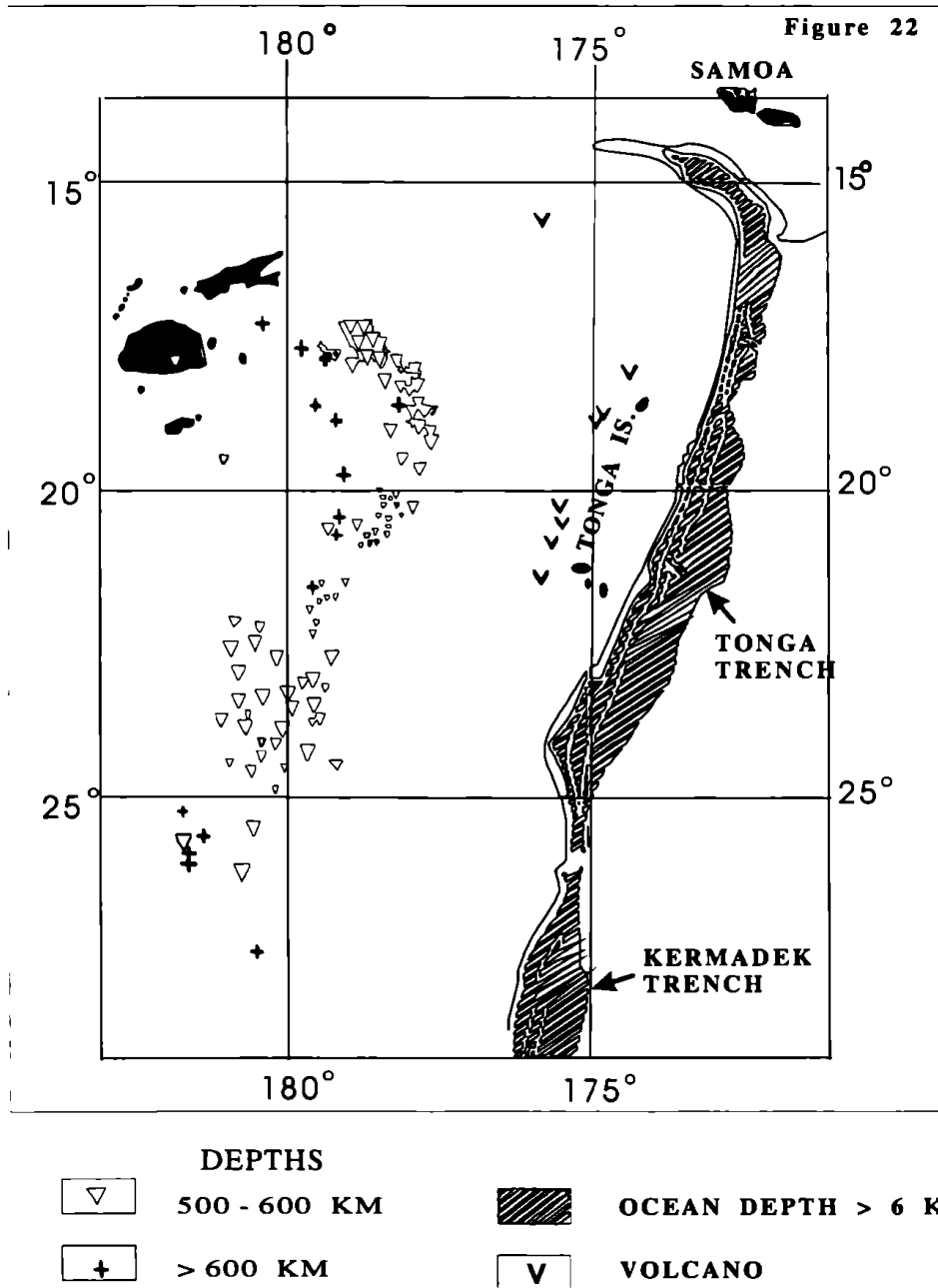
6.3 Experiments in the modelling of fold zones

The proposed geosynclinal mechanism has provoked strong criticism for allegedly failing to account for the observed types of folding and regular patterns of fold distribution in geosynclinal belts. This criticism compelled us to attempt experimental modelling.

SEDIMENTS

Figure 23

THE BREAKUP OF A CRYSTALLINE BASEMENT
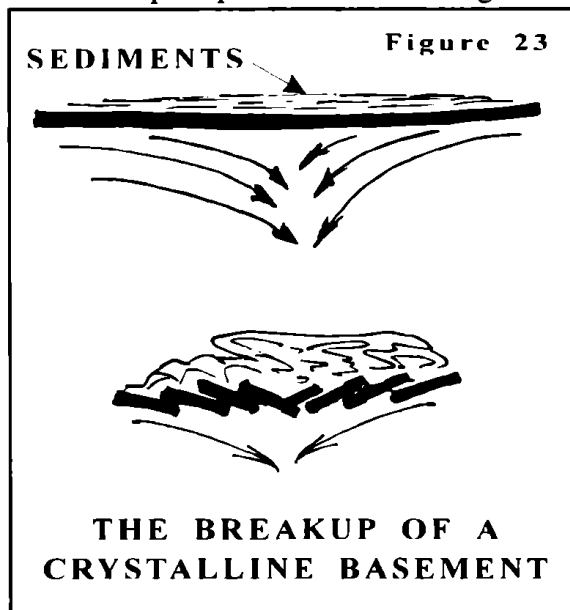
The idea of the experiment was to determine the type of wrinkling that would occur in plastic masses subjected to reduc-tion of the area of their basal underpinnings, the basement they lie on, so to speak. This experiment would be equivalent to reducing the cross-section of a geosyn-clinal belt. From inception the model allowed for imbrication of its upper, rigid layer (the lithosphere) on which young, malleable sediments rest. Such imbri-cation may be regarded as the reaction of the "crystalline basement" of a geosynclinal basin to viscoplastic flow in underlying horizons (Figure 23). This procedure was considered the best way to verify the hypothetical connection between geosynclinal folding and reduction in width of a geosyncline (the relationship that follows from our concept). Although this connection follows from our concept, it remains the subject of lengthy and heated debate.

The structure of the original model: The original model was a thin-layered stack of varicolored plasticine placed on paper strips (Figure 24). The stack extended to: 45-50 cm in length by 5.5-6.0 cm in width, and 0.8-1.1. cm in thickness.

The principle of the experiment: When the model with its stack of plasticine layers that had been set down on paper strips was ready, it was heated to a state close to melting. Heating of this sort can be done in a drying cabinet, gas oven, or on a steam-heating radiator. The last method proved best, because heating then was from below, thus approximating natural conditions. With the heated stack on a flat surface, tips of the paper strips were tucked into and drawn through a slot narrow enough to restrain plasticine from following. This procedure reduced the basal area of the stack, the "basement" so to speak, while allowing the plastic mass to wrinkle into folds. Such basal reduction would seem to follow closely the narrowing of geosynclines by the infilling of the underlying funnel-like depression (Figure 18).

After cooling, the model was cut lengthwise into a series of sections simulating cross-sections of fold belts. These sections were then studied.

Choice of **parameters** to maintain similarity:

Figure 24

paper strips

plastic material

THE MAKEUP OF THE INTERPRETIVE MODEL
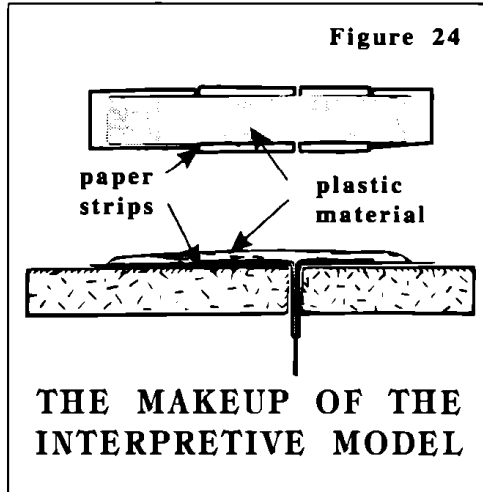
The criterion of similarity in the modelling of visco-plastic deformations is satisfied by the formula $C_n = C_d \cdot C_g \cdot C_l \cdot C_t$, where C is the ratio between the respective modelled and natural parameters: n = viscosity, d = density, g = free fall acceleration, l = length, and t = time (Gzovskii 1963).

In the natural fold-generating processes of geosynclines, the parameters were taken as follows: $n = 10^{19}$ Pa·sec, $d = 2.6$ g/cm^3, $g = 10$ m/sec^2, $l = n \cdot 10^7$ cm, $t = n \cdot 10^{13}$ sec (millions of years). Density, gravity, and linear dimensions of the experiment are non-variable ($d = 1.8$ g/cm^3, $g = 10$ m/sec^2, $l = n \cdot 10^1$ cm).[9] Time for the experiment in our case is limited by the capacity of the plasticine to "cure" in a few minutes ($t = n \cdot 10^2$ sec) after the heat is turned off. Hence, conditions of similarity of plasticine models to natural conditions can be fulfilled only by changing viscosity. Putting the modelled and natural parameters in the above equation, we find that the viscosity that satisfies the similarity condition is $n = 10^2$ Pa·sec.

A special viscosity gauge was used to maintain the temperature at 55-60°C, the viscosity required to maintain similarity. Hence, the original models were heated to that temperature.

Results:

The experiments showed that the type of folding, given the condition for similarity, depends on the scale of reduction of model length and the rate of differential reduction lengthwise in the model. Trial and error were used to establish the conditions which lead to folded structures of the Great Caucasus and Alpine types (Figure 25). Fundamental to the experiment is the notion that shingle-like overlapping of the geosynclinal "basement," imbrication in customary parlance, must occur to accommodate the accumulated sedimentary column. The initial and ultimate positions of the paper strips under the plasticine determine the type of imbrication and the final configurations of the resulting fold structures.

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[9] *Fabrication of models more than 50 cm long is complicated and leads to the* **paper strips ripping** *off as they are drawn* **through the slot.**

α

Figure 25

Great Caucasus style compression

β

Alpine style compression

The bracket is explained in the text.

COMPARTMENTALIZATION AND PATTERN OF RUPTURE OF THE TEST MODEL
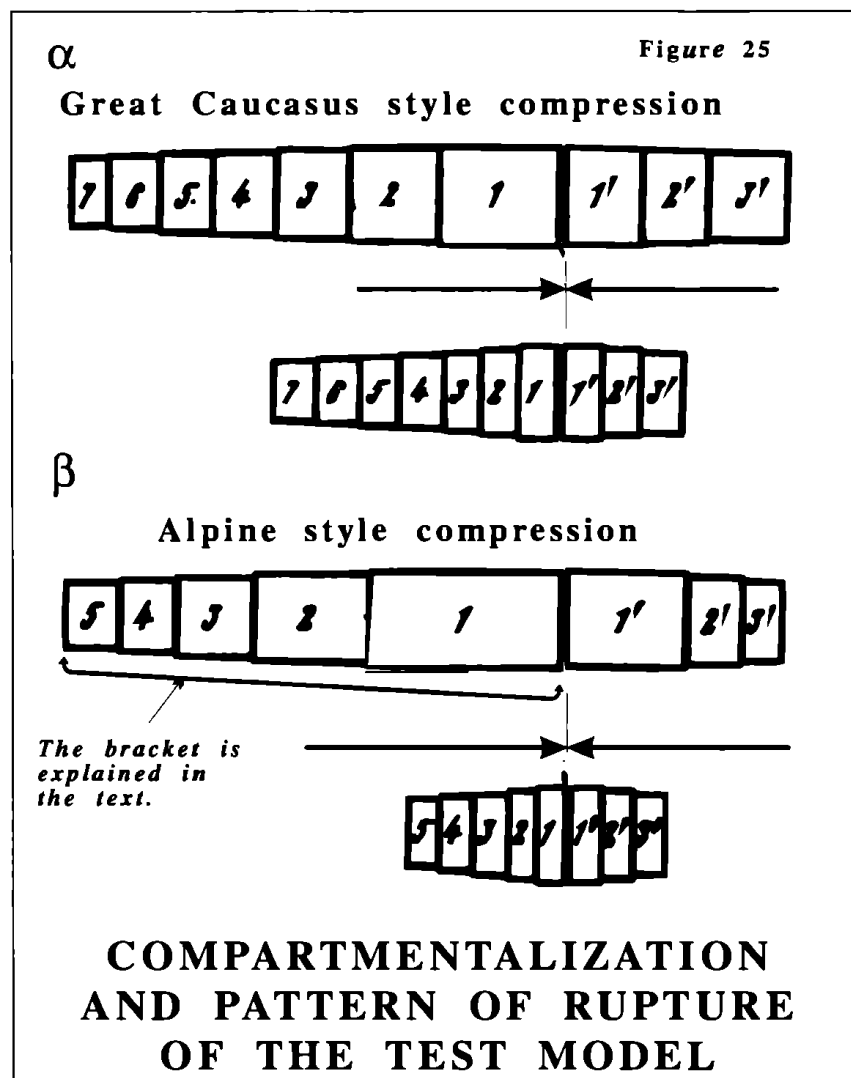
Figure 26   _GREAT. CAUCUSUS MODELS_

  a)   *The variant with diapiric axes*
  b)   *The imbrication model where slabs from the core of the orogen are stacked one against another at the mountain front*
  c)   *The "great cover" model, an overthrust anticlinorium*
  d)   *The "embryonic cover" over a squeezed core*

Figure 26a
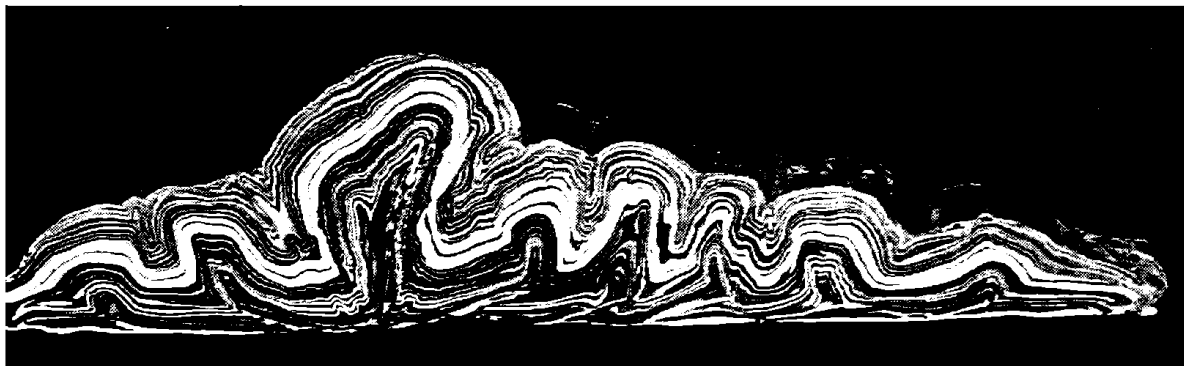

Figure 26b

Figure 26c

Figure 26d

Figure 27a

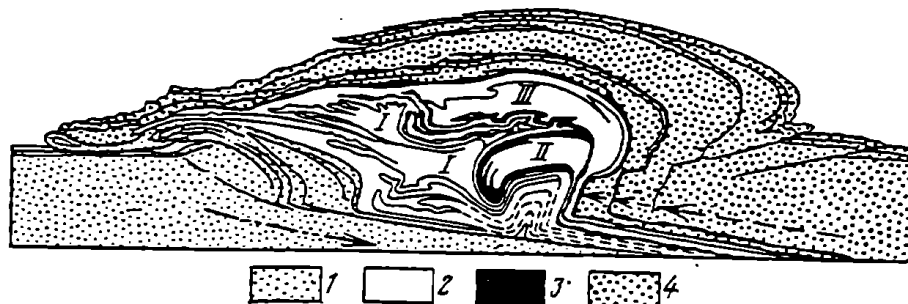Figure 27b

Figure 27c

Figure 28

Figure 27 ALTERNATIVE ALPINE MODELS

    a) The cover behavior over flowage folds

    b) Intercalation of overthrust folds and plate covers (on left) and
    lens-like compression of "ancient structures" (on right)

    c) The overlapping of two gigantic thrust sheets, each of them
    complicated by folding

Figure 28

_____   *1*   *The Eurasian foreland*

_____   *2*   *Pennine cover: the Alpine geosynclinal stage*

■■■   *3*   *Ultramafic rocks*

░░░   *4*   *Overriding African blocks and more easterly*
           Alpine terranes

I   *Great St. Bernard cover*

II   *Monte Rosa cover*

III   *Dan-Blanc cover*

Structures of the Great Caucasus type (Figure 26) result from the reduction of model length by 1.6-1.8 times (as in Figure 25a). Cross-sections show the basic features established for the Greater Caucasus folding (Sorskii 1962; Sholpo 1964; Figure 26a, -b). These are levels of folding that rise regularly toward the "principal ridge." Folds get more complex from the peripheries to the axial zones (from simple box folds to strained isoclinal folds). An axial "diapir," with ancient, intricate folds, commonly with traces of flowage, breaks upward to the elevations of younger sequences. Finally, nappes verge outward on both sides of the axial zone. An additional feature is the incidence of increased stress in synformal folds as contrasted with relative simplicity of folding on antiformal axes. As described by many scholars, crushed bedding in synclines is typical of fold belts. Some models (above zones of divergence) have yielded the characteristic pattern of the "principal ridge" (Figure 26b), while in other cases, the axial zone for some reason squeezed off a nappe in the form of a huge recumbent fold (Figure 26c). The reason for the structural diversity is probably variation of viscosity, which in our experiments could not be maintained strictly within the limits prescribed. Figure 26d, shows the initial stages of nappe formation from the "compressional core."

Alpine-type structures (Figure 27) result from the reduction of model length by 2.5-3.0 times, as distinguished in Figure 25b. Under given conditions, in the final models a variety of nappe structures are shown as systems of nappes in conjugations of recumbent folds, thrust sheets, and combinations

thereof. Thrust sheets are found mainly to appear with uneven heating of the models. In one experiment in particular, the optimum temperature was applied to the portion of the model that experienced the largest length reduction (brackets in Figure 25b). The rest of the model was at temperatures of 40-45°C, and hence had higher viscosity. This provided "competence" to the layers as the "autocthon" was underthrust beneath them. The result was that the entire zone of wrinkling in the experiment comprised giant thrust sheets, which in turn were compounded by recumbent folding. Evidently these results simulate natural occurrences, where both vertical and horizontal variation is the order. It is no accident, then, that the model resulting from experimentation simulates the classical generalized profiles of the Alps (Figure 28, after Rutten, 1972).

Interestingly, while the results for the Alpine models were not unexpected, the implied connection between Caucasian structures and basal plane shortening was unexpected and stands in contradiction to current ideas of fold genesis and fault dislocation in that terrane. It is theorized (Sorskii 1962; Belousov 1975) that Great Caucasus structure, with simple, widely-separated box folds, is produced by vertical tectonics, whereas the complex folding in its axial zones results from density inversion and consequent diapiric intrusion of deep-sourced material.

Our experimentation shows that box folds develop in association with overthrusts (or underthrusts, which are mechanically identical). When thrusting is relaxed, not infrequently bedding is flexed in a trunk shape (Figure 26). The "diapir," according to modelling, is "squeezed-out core" from the axial zone of the fold belt, the zone beneath which the basement area has been most reduced by imbrication. Caucasian structures, with their squeezed axial cores and relatively simple limbs, are generated not so much by differential vertical block movements as by tangential shear from deeper horizons close to the center of the underthrust folded series. Compressive underthrusting of deep-seated horizons has the same effect as the compression of superior surfaces, an effect that is widely acknowledged as the prime cause of Alpine structures (Ruzhentsev 1971). Hence, the mode of genesis of Great Caucasus-type structure is identical to that of Alpine structure. The sole difference between them is the magnitude of basal compression, which for the Great Caucasus is less than its Alpine counterpart by one-half, according to our experimental results.

6.4 Deep-Earth origins of planetary geodynamic evolution

The evolutionary course of tectono-magmatic activity from the initial stages of planetary history to Phanerozoic time has been intricate and is irreversible. The most distinctive of geodynamic regimes was that of the early Archean, when mafic compositions and granulite metamorphic facies predominated in petrology, linear tectonic orientations ("belts" in current terminology) were absent, and ovoid or rounded features of subsidence were

numerous. These rounded features are bowl-like forms that appear as chaotic "...ring-shaped, oval, loop-shaped ...synforms separated by narrow, occasionally topographical domes or brachyal antiforms" (Pavlovskii 1975).

The oldest members of the world's largest anorthosite massifs have mafic compositions and exhibit circular structural forms. These features are now recognized as characteristic of the earliest era in Earth history – an unique "lunar" stage – the "Katarchean" of Glukhovskii & Pavlovskii (1973). The circular structural patterns of this age suggest a regime of small-cell convection (Glukhovskii et al. 1977). This deduction accommodates the observation that sharply-defined vertical and lateral variations in the geothermal gradient were already established. These convective phenomena may be evidence that there was instability in the early Archean lithosphere (Engel 1974).

Later in the Archean, the lithosphere became more stable, as evidenced by the appearance of large intrusive massifs, among them 3.3-3.5 Ga-old granitoids (Pavlovskii 1975). Their emplacement marked the first sign of an emerging granitic crustal layer. Where the early granitoids, characteristically with low-K and primary enderbite, were sporadic; and the crust remained largely mafic, later in the Archean, metamorphism became more diverse so that, along with granulites, scattered sediments were deposited. Nevertheless, these now-metamorphosed rocks still do not exceed the greenschist facies in volume. Today they are found with original structural and tectonic signatures in such places as Swaziland, Zimbabwe, and the Canadian shield. Everywhere, the features left from the geodynamic regime of that era are persistently irregular in orientation and form. Ye V. Pavlovskii proposed the name "nuclear" for this crustal stage.

The close of the Archean was marked by perturbation of the existing tectonic regime on a massive scale. Archean mafic basement was pervasively affected by an intense pulse of potassium granitization.[10] The granite layer of Earth's crust was initiated and commenced to evolve and expand at this time. Typically Archean, anhydrous granulites gave way everywhere to the hydrous metamorphism of greenschist and amphibolite facies. Commencing in early Proterozoic time, geothermal gradients decreased rapidly (Engel 1974), lithosphere stability increased, and sedimentation acquired a "proto-platform" character (after Pavlovskii).

The variably granitized Archean mafic basement received a terrigenous depositional cover clastic, volcanic, or other rock. Examples of such cover include the Udokan series of eastern Siberia, the Yatulian of Karelia, and the Dominion reef and Witwatersrand in South Africa. However, sedimentation under these conditions, in contrast to that of the platforms of the Neogaikum, was accompanied by high-grade metamorphism (up to amphibolite grade) and intense granitization of the Archean mafic basement and its protoplatformal cover (Pavlovskii 1975). The altered cover was then subject to folding on

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[10] *Editor's Note: Reviewers have queried whether the author means metasomatic granitization. He does.*

the peripheries of its growing granite-gneiss domes.

The fundamental manifestation of perturbation of the tectonic regime was the emergence of extended linear features, which expressed the existence of horizontally-directed fields of stress and deformation (Pavlovskii & Markov 1963). These structural features have been called "Timiskaming furrows" on the Canadian shield (Markov 1962), "paleoaulacogens" (Leites et al. 1970), and "suture troughs" (Glukovski et al. 1976) on the Aldan shield. These and similar formations were first recorded in geological history at the Archean-Proterozoic boundary and have been accepted into the literature as "greenstone belts." Greenstone belts differ from Phanerozoic geosynclinal fold belts (Markov 1962) in being smaller in area, relatively simple in internal structure (without observed differentiation into geanticlinal or intra-geosynclinal zones), absence of foredeeps, and a reduced tendency toward orogenesis (absence of typical molasse). However, despite small present areal extent, greenstone belts must have covered the Archean - lower Proterozoic surface of the planet (Glukhovskii et al. 1977). Researchers tend to view them as prototypes for later geosynclines of Neogaikum. A reason for this is that they increased in size progressively over time, while their overall number declined. Another reason is that their internal structure became more complex, until, starting with the latest Proterozoic (Riphean), typical molasse began to be found in them. In fact, since the first molasse in mid-Proterozoic time, greenstone belts have acquired all the major features specific to Phanerozoic fold belts, both in terms of tectonic evolution and in type of magmatism.

Simultaneously with the evolution of greenstone belts, intense granitization of the crust continued through the early- and part of the middle-Proterozoic. As a result, about 80 percent of the area of the present continental crust dates back to this span of time, making this period the main stage of granitization and granite formation in all of Earth's history.

Since the end of middle Proterozoic time (Neogaikum), the structural-tectonic environment and geodynamic regimes have been distinguished by huge stable blocks or platforms separated by mobile geosynclinal belts. Concomitantly, the number of geosynclinal belts continued to shrink as lengths of surviving belts grew. This was especially typical of Proterozoic greenstone belts, in which, with every new tectonomagmatic cycle, the geosynclinal zones expanded and their number decreased. Basically, one may pose as a generalization of fold belts that, progressing from older cycles to younger ones (Khain 1964), there is more diversity of tectonic movement and intensity, more tectonic foreshortening, and more mountain building, while duration of the episodes declined for unknown reasons. Processes of granitization and metamorphism at this stage were confined to fold belts. On platforms in quiet tectonic periods sedimentary cover accumulates. By contrast, from the end of the Paleozoic, and increasingly in Meso-Cenozoic times, platforms became the venue of vigorous tectonic, tectono-magmatic, and magmatic events (riftogenesis, zones of activation, and eruption of trapps).

Thus, geodynamic regimes during Earth's history *have* changed in a

radical fashion. In a generalized overview, three types of regimes can be identified with particular stages of the history of the planet: (1) An Archean pre-geosynclinal period, characterized by high geothermal gradients, anhydrous granulite metamorphism, and fine-cell convection (especially typical of Katarchean and less so of late Archean); (2) The Proterozoic, marked by proto-geosynclinal greenstone belts, which were actually the main stage in formation of the granitic layer of the crust; and finally, (3) the Riphean-Phanerozoic stage of the platform-geosyncline type of evolution of the Earth. The origin of oceans in this stage is discussed separately below.

Let us look into the probable causes for evolution through these geodynamic regimes in the light of our hypothesis of the primordially hydridic Earth. For Archean time it is necessary to account for rapid heating of the planet in order to explain energetic convection, anhydrous, highly-reducing fluids, and the presence of high-pressure mineral formations at shallow depths. We start by looking for a source capable of producing the rapid heating of (at least) the outer geospheres of the planet. Studies of the earlier Archean indicate higher-temperature styles of metamorphism and higher geothermal gradients in the outer geosphere. Manifestly, there must have been a ready source of heat to energize early geological evolution on Earth. A possible source for this early heat is indicated by the surprisingly early formation of the anorthosite *sic* crust of the Moon. This occurred at 4.3-4.4. Ga, or virtually right after the completion of lunar accretion.[11] Clearly, radiogenic heat would have been insufficient. It can be shown by calculation that even with concentrations of radiogenic elements an order of magnitude higher than we find in chondrites, the heat generative ability of the body of a planet would not have been sufficient for the rapid heating that actually occurred on either the Earth or the Moon.

Two further facts that need to be taken into account are fine-cell convection, which suggests that heating involved *only* the outer shell of the Earth, and the abrupt lowering of the geothermal gradient at the Archean-Proterozoic boundary. These two facts are inconsistent with a radiogenic origin of heat, because such an origin would not have been able to provide selective heating for the outer geosphere of a homogeneous planet, which had not undergone differentiation. It would be difficult to reconcile suddenly-reduced geothermal gradients with a slowly-diminishing heat source that was evolving from naturally decaying long-lived isotopes.

The hypothesis of a primordially hydridic Earth, on the other hand, accommodates conceptual rapid heating of the outer geosphere as a function of the expulsion of oxygen from the interior by "hydrogen purging" and consequential formation of the silicate-oxide shell of the Earth. Thermodynamic

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[11] *It bears remembering that the supernova explosion, which was the last stage of nucleosynthesis that gave rise to the Solar system, is dated to 4.57 Ga.*

calculations show that with elevated pressures, the exothermal effect of oxidation reactions is progressively reduced to naught. In the case of SiO_2, a reversal of sign of the thermal effect (passing zero value) is observed in the region of 40 GPa (Kuskov & Khitarov 1976; 1977).

According to these data, oxygen released from the Earth's interior must be held in chemical bonding only in the outer geosphere, where oxidizing reactions must have released large amounts of heat. Because the 40 GPa isobar in the Archean (on the basis of our estimate of the original radius of the planet) must have occurred approximately at a depth of 350-400 km, the thickness of the silicon-oxide shell, which was generated largely in the Archean, could not have exceeded that observational range of depths. Interestingly, 350-400 km is the depth of Gutenberg's 20° transition, which in our model is equated with the change from the silicate-oxide to the intermetallic state in the mantle.(Chapter III, 4). Thus, heat-producing oxygen bonding in the upper geosphere must have been responsible for the rapidly-rising geothermal gradients and for the fine-celled convection at early stages of planetary history. Convection should have been fine-celled, because it was limited to a relatively narrow range of depths: 350-400 km maximum.

Convective comingling in the outer shell must have induced uniformity of distribution to the oxygen that arrived from below. Due to this comingling, residual components of the original Earth are unlikely to be preserved in the silicate-oxide shell. Furthermore, the impetus to uniformity may provide the explanation for the anhydrous nature of Archean metamorphism. In reactions of oxidation involving Si, Mg, Ca, Al, and other common petrogenetic elements before the stage at which they are oxidized completely, the partial pressure of water in the system remains extremely low. Such reactions are employed in laboratory procedures by providing a "hydrogen buffer," a suppressor of the activity of water and oxygen.

It follows naturally that original conditions on the planet, in light of our model, automatically account for the "geobarometric" and "geothermal" paradoxes of the Archean. By accepting invariance of Earth's radius, the traditional point of view, one must accept that regional Archean granulites were formed at depths of 25-30 km, where the lithostatic load imparts pressures as high as 0.8-1.0 GPa, the pressures required to produce the granulite mineral assemblages. Consequently, the traditional view holds that these high-grade metamorphic rocks were exposed to erosion by the time the unconsolidated sedimentary cover began to accumulate.

However, the ancient platforms comprise more than one-half the area of all modern continents. The traditional view then leads into enigma. How could huge quantities of terrigenous material have been submerged and buried under younger materials? The paradox vanishes when we admit Earth expansion into our thinking (Lishnevsky & Krementskii 1975; and some others). Our estimates of probable expansion of the planet impute a force of gravity in Archean time triple its present level (Chapter VII. 1-2). With gravity of that magnitude, pressures as high as one GPa would have

prevailed at about 10 km depth, thus resolving the burial enigma.

By recognizing Earth expansion, we dispose of the "geothermal paradox" as well. This is the paradox that arises from the traditional view that granulite temperatures of about 700°C occurred at depths of 25-30 km, and therefore, that the Archean geothermal gradient was barely 23-28°C/km, much below present levels. The known Archean radiogenic heat regime was several times higher than today. However, if the temperature of 700°C actually did prevail at the lesser depths of 8-10 km, then the Archean geothermal gradient of 2.5-3.0 times the present level is reasonable, and the paradox disappears.

Archean formations sometimes include blocks of pyrope peridotites and eclogites containing diamonds (Peive et al. 1976). These mineral compositions and the diamonds impute pressures at multiple GPa levels ("nGPa"). However, as these rocks are in the crust, they require special accounting. In our theory, such occurrences can be attributed to convection in the silicate-oxide shell, when individual blocks of abyssal, high-pressure formation may rise in a metastable state from the mantle interior to near-surface levels and survive to our time in pristine crystalline condition. The hypothesis of the primordially hydridic Earth providing for minimal presence or absence of water accompanied by high temperature and pressure gradients in the initial stages of planetary history must have favored diamond formation below depths of about 30-40 km, and at pressures of about 3-4 GPa.

Our hypothesis appears to support the recommendation of Peive and colleagues (1976) that surveys and prospecting for diamonds should be done in Archean terranes, especially early Archean terranes that have escaped retrograde metamorphism (diaphthoresis) and thus, are intact and unaffected by oxidizing fluids that might have corroded and dissolved diamond.

In this light another problem arises. Archean granulites have usually been regarded as products of the progressive metamorphism of initially sedimentary or volcanic sequences. In our model, which allows for convective movements in the silicate-oxide shell at early stages of planetary development, Archean granulites could have resulted from diaphthoresis of deep-seated eclogites, which had been expelled into the crust from the mantle convectively and then exposed to regressive metamorphism. This viewpoint is supported by the discovery in granulites of evidence for high-pressure mineral dissociation. Sapphirine in particular, in association with sillimanite and orthopyroxenes of the Sutam series of Southern Aldan, is attributed to the decomposition of Mg-rich pyrope by Kolesnik and Koroluk (1976).. Other researchers ascribe it to a transition induced by decline of pressure as eclogite is transformed to granulite facies.

M.Yu. Khotin, in a personal communication, has reported finding xenolith-like inclusions with clear-cut textures of solid-solution decomposition in anorthosites of the early Archean granulite schists and gneisses beneath the Dzhugdzhur Massif. Subsequent studies have shown that the original mineral was garnet, which is stable in a range of pressures above 2.5 GPa. Moreover, there is interesting information on the hexagonal polymorph of diamond,

lonsdalcite, which has been found in eclogites of the southern Urals and Kola Peninsula (Golovnya et al. 1977). If these diamonds are not cosmogenic (produced explosively by impacts of large meteorites), they must attest to the expulsion of the host eclogites from depths exceeding 100 km, because lonsdaleite forms at pressures greater than 13 GPa, a scenario that is impossible without invoking convective comingling in the silicate-oxide shell at early stages of Earth history.[12] Of course, this possibility does not rule out accumulation of volcanic and clastic (seismogenic) sequences in the early Archean, which sequences could have undergone later metamorphism to granulite and eclogite facies in the down-flowing limbs of convective cells.

Hence, the specifics of the Archean in our model are wholly attibuted to the formation of the silicate-oxide shell of the primordially hydridic Earth. Clearly, this geosphere must have been built gradually downward. At increasing depths and pressures the exothermic processes of oxidation diminish, and convective movements wane. These changes offer an explanation for the chaotic distribution and orientation of ancient structures. Convection, as we understand it, could not possibly have been stationary because its basic source of heat must have migrated constantly. When one zone was fully oxidized and no longer generating heat, exothermic oxidation must have spread to other rock volumes, and convective cell positions should have wandered responsively.

We tend to think that the Archean-Proterozoic boundary was marked by a high level of oxidation of the rock-forming elements of the outer geosphere. This oxidation appears to be reflected in the ubiquitous effects of oxidizing fluids (water and oxides of carbon especially), and by the onset of amphibolite metamorphism. Large-scale, early-Proterozoic K-granitization and magmatic granite formation are discussed below, and provide rationales for the correlative phenomenon, the source of potassium and other lithophilic elements that are required to generate granitic crust.

Evidently, decreased exothermal oxidation reactions in the outer geosphere of the Earth by the late Archean time had resulted in a decline of temperatures in the silicate-oxide shell as well as the solidification of the lithosphere. This allowed oriented fields of deformation, linearly-oriented structures, that is to say, to develop. The dense network of lower Proterozoic greenstone belts in our model is consequential upon planetary expansion, which ended with a pressure regime of 10-100 GPa and the absorption of much of the available heat. This expansion also inexorably changed the thermal regime of the inner geospheres in a radical way. Altered thermal regimes along with reduced oxidation explain the rapidly-declining geothermal gradients of the Archean-Proterozoic boundary as well as the concurrent stabilization of the lithosphere.

From early Proterozoic time, planetary expansion has driven geodynamics

[12] *Golovny and colleagues (1977) note that a mantle provenance for eclogites was earlier advocated by I.S. Yefimov and B.N. Naidenov on theoretical grounds.*

throughout the entire span of Earth history. One of the aspects of greenstone belt evolution that is preserved in the Neogaikum fold belts is the progressive enlargement of linear structures and the commensurate decline in their numbers. This may be attributed to the establishment of a common network of extension structures, along with increasing mantle thickness and diminishing core radius. Another way of putting this is to assert that the decompaction front moved steadily deeper into the planet (Chapter VI, 1). All other forms of tectono-magmatic evolution of the Proterozoic and Riphean-Phanerozoic eras, along with those listed above, are attributed in our hypothesis to variations in the flux of hydrogen escaping from the interior as Earth's mantle thickened.

Next to be discussed is the style of propagation of proton hydrogen in the body of modern Earth. Its pattern of ambience should vary significantly from the core to the outer geospheres. Deep in the mantle, "evaporating" hydrogen must be represented by a uniform cloud of proton gas enveloping the core. As hydrogen escapes, the initially uniform cloud should become channelled into discrete, denser flows. These streams, as they percolate through the mantle, should tend to coalesce into fewer and larger channels (Figure 29), and ultimately to flow together in what we designate as "tectonogenes." (1) The capture of smaller streams by larger ones happens because the larger streams are the hotter and, hence, have higher diffusion rates. The phenomenon can be likened to the well-known capture of creeks by rivers. (2) Magnetic attraction occurs between parallel flows of proton gas, a similar effect to that of parallel electrical conductors carrying direct currents.
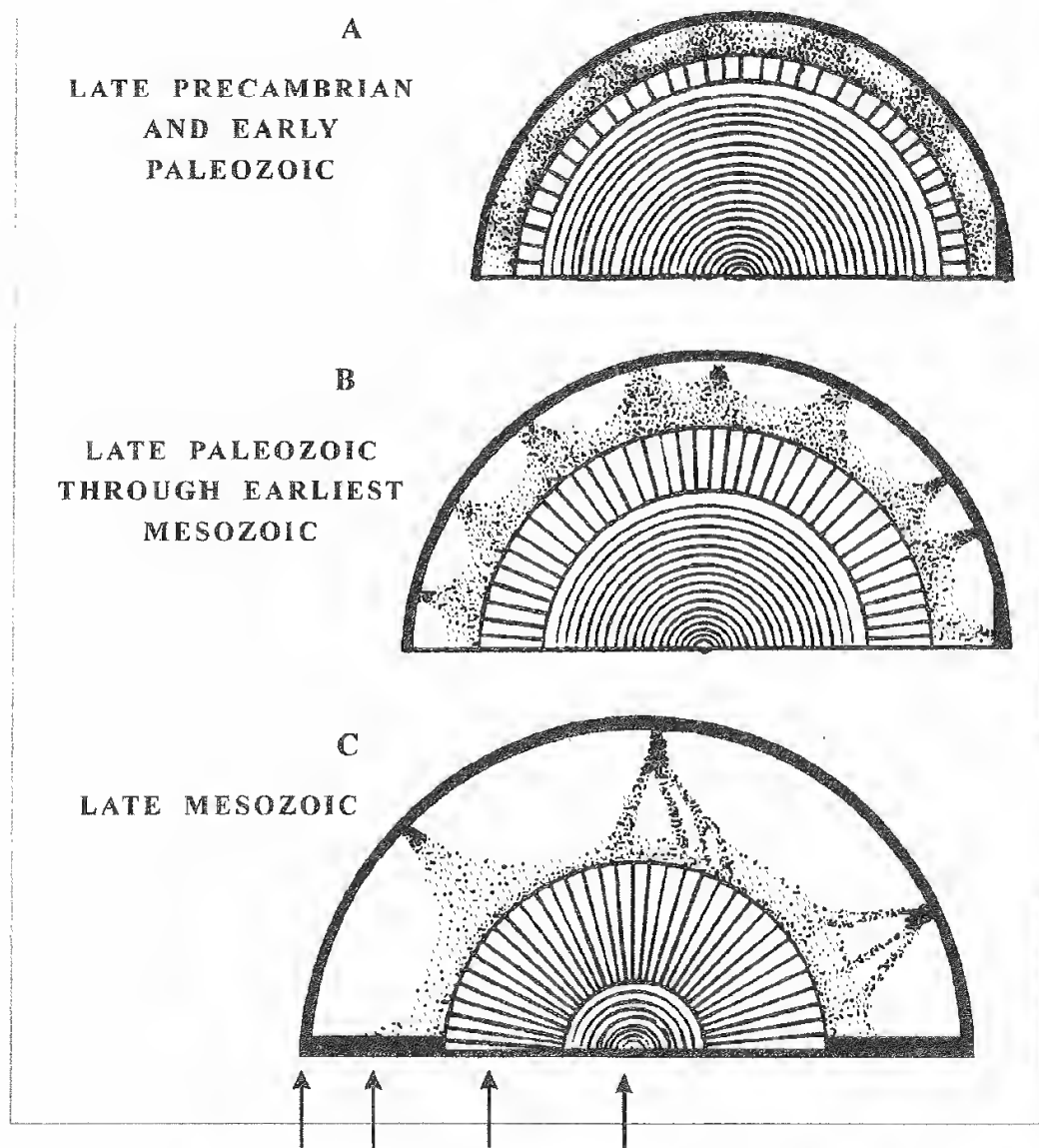
The precursor schematics of hydrogen degassing from the core may help to account timewise for the specific patterns of hydrogen flow and, hence, to allow us to put our finger on what has actually caused the development of tectonomagmatic activity throughout the history of the planet. Near the Archean-Proterozoic transition, both before and after it, the major period of Earth expansion occurred. The mantle was thin, and the hydrogen flux failed to divide into discrete streams (Figure 29a). Uniformity of flow can be invoked to explain the all-pervasive tectonism and magmatism that convulsed the Archean Earth and led to Proterozoic granitization on continental scales.

As the Earth expanded, however, and the mantle thickened, the ubiquitous hydrogen proton flood differentiated into separate "jets," tectonomagmatic activity was localized into isolated zones separated by stable blocks. This separation, we think, is the precursive activity that led to the present regime of platform-geosynclinal geodynamics in the Neogaikum, where all tectono-magmatic activity, along with granitization, became concentrated in fold belts. The merging of smaller streams of hydrogen into larger channelways is seen as a simplification of the flow pattern into the general structures of extension tectonics. This scenario, in turn, was the result of the expansion of the Earth and the migration of the decompaction front deeper into the planet. The pattern of hydrogen propagation paths must, then, have depended on the planetary system of relative tectonic tension. Naturally, as hydrogen migrated into large channels, the degree of saturation of tectonogenes with proton

hydrogen would have increased over time, thus leading to more disparity between belts of compression and decompression within the channels. This differentiation is thought to be responsible for tectonic diversities and the increasingly complex imbrication and orogenesis of later, as contrasted with earlier, periods.

Figure 29

REGIMENS OF HYDROGEN EFFUSION IN SUCCESSIVE GEOLOGICAL ERAS

A

LATE PRECAMBRIAN AND EARLY PALEOZOIC

B

LATE PALEOZOIC THROUGH EARLIEST MESOZOIC

C

LATE MESOZOIC

1) Silicates and oxides of the outermost geosphere; 2) metallic mantle + effusing hydrogen; 3) liquid outer core; 4) hydridic inner core.

Ongoing coalescence of hydrogen flows within a single tectonogene would produce individually denser jets. These jets could have been distributed among throats of various depths along the strike of a geosyncline; and the differentiation would have led to variations in the nature of imbrication within the fold belt, as well as to intermontane depressions at the orogenic stage (Chapter VI, 2).

In keeping with our hypothesis of geodynamic evolution, the transition from Archean to Proterozoic must have been abrupt and cataclysmic, both in tectonic specifics and style of petrogenesis. If the same criteria are applied in later times, typical transformations of Proterozoic greenstone terranes in Riphean-Phanerozoic geosynclinal belts should have been smoothly evolutionary. Indeed, it does appear to be a truism that the Archean-Proterozoic boundary represented a first order planetary perturbation, which gave Earth the first linearly-oriented mega-structures and the most intense granitization in geological history. By contrast, later episodes of mutation of greenstone belts into geosynclinal belts (with synchronous and indigenous granite formation) were quite gradual. The separation between these eras of geodynamics is set somewhat arbitrarily to coincide roughly with the Middle Proterozoic-Riphean boundary.

Now we move on to the reason for cyclicity in tectogenesis. In our hypothesis this reason is reduced to the single cause of temporally-discrete, pulse-like flows of hydrogen from the Earth's core. Definition of the phenomenon can be attempted only to a first order of approximation. The nature of hydrogen interaction with metals (Chapter V, 3) suggests that expansion of the core could not have proceeded unless its hydrogen concentration had been reduced somewhat, by an "initial degassing," in effect. Degassing would seem to require a rise of temperature, there being no other apparent way to separate hydrogen from Earth's core. However, temperature cannot rise during core expansion, because expansion, at pressures typical of inner geospheres, requires enormous energy input. Thus, our geochemical model of the Earth suggests that hydrogen degassing and planetary expansion should have been separated in time.

Let us consider how this hiatus may apply to the evolution of the interior of the primordially hydridic Earth. Dissociation of hydrides could have started only when a specific high-temperature level was reached. Let us assume that this temperature was achieved from radiogenic heating in a specific volume of the core and that it triggered dissociation of hydrides. We will show in Chapter X that the process of hydride dissociation can proceed only with release of much heat. This heat, however, would not have led to a sudden escape of the entire hydride component from the core, because hydride dissociation entails an increase of the ambient hydrogen pressure, and that would inhibit further dissociation. As in any chemical reaction, abrupt pressure increase, due to volume increase of decay products, inhibits further thermal decomposition.

Vigorous hydrogen degassing must have been a consequence of core heating and pressure elevation caused by the increased flux of ambient proton hydrogen. This flux would have continued so long as hydrogen concentration in the outer zone of the core did not decrease to the point where reduced proton intrusions into atomic electron shells precluded the retention of metals in densified form (Chapter V, 3). At that point the core boundary would be forced downward by decompaction while mantle thickness increased. With the onset of decompaction (because this process absorbs huge quantities of energy), core temperature should have fallen abruptly and reduced the level of hydrogen degassing. After the process of planetary expansion was completed, the entire cycle would then repeat itself.

Figure 30

DISTRIBUTION OF THE GLOBAL
VOLUME AMONG SPHERES
OF ONE-TENTH RADIUS
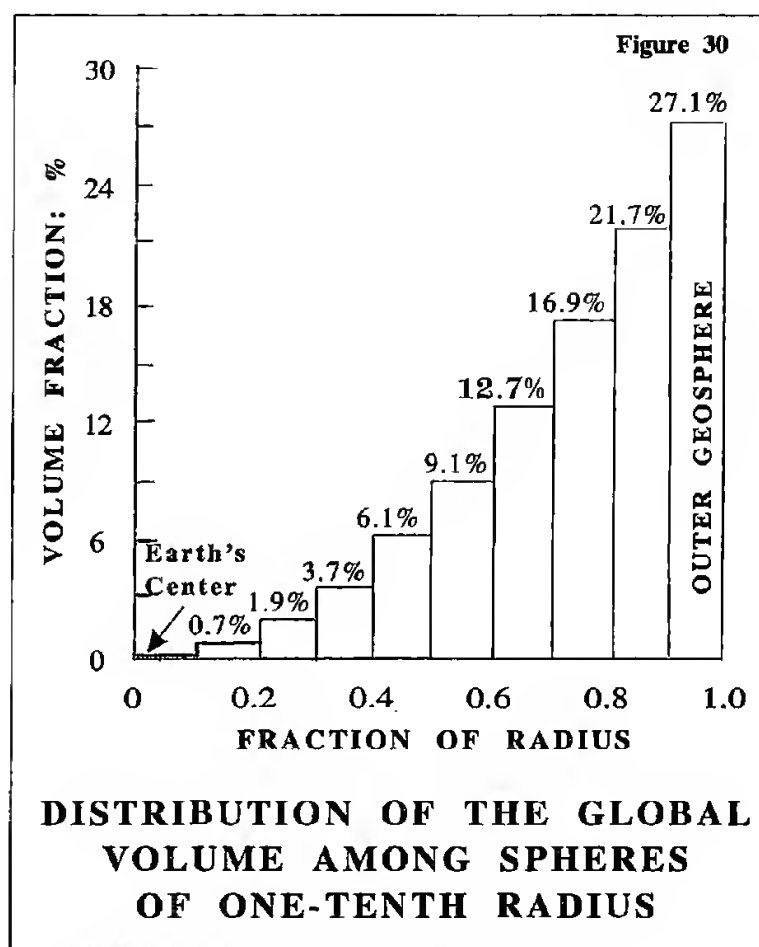
Thus it is that the cycle, which started with the decomposition of hydrides, led to heating and higher pressures from proton hydrogen in the outer sphere of the inner core. That process resulted in vigorous degassing and subsequent decompaction of the outer zone of the core. Consequentially, with every new cycle the outer/inner core boundary moved some distance closer to the center of the planet. It is readily apparent that this cyclic rhythm is dependent on the systematics of hydride separation in the most central zone of the planet, the inner core. If hydrides are resistant to

dissociation in a linear relationship with pressure, the inner-core boundary should sink approximately the same distance with every cycle, although volumetrically the matter involved in decomposition decreased significantly from earlier to later cycles (Figure 30). Because of this decrease, the duration of degassing and decomposition episodes should have decreased along with the associated tectonomagmatic cycles.

Presently, the inner core accounts for less than one percent of planetary volume. The implicit magnitude by which the hydride reservoir in the core has been reduced implies ongoing disturbance of earlier regimes of cyclicity in the Phanerozoic and future Earth. It may not therefore, be concluded that the Alpine cycle was the last full geosynclinal cycle in the history of the Earth, because the Phanerozoic tectonomagmatic cyclicity has been disrupted, and the modern stage is but a transition to a new geodynamic regime. Such a regime is to be expected in the near future, speaking in geological timescales, because the hydride reservoir within the planet has largely disappeared. Ours will be a planet without an inner core.
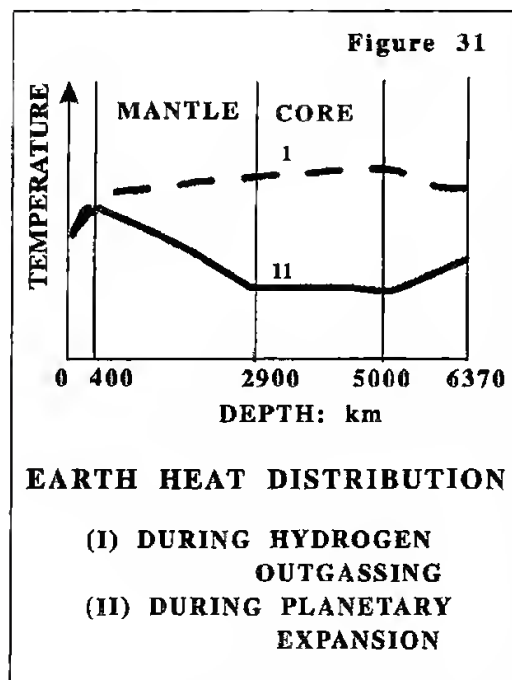
One could try to describe the features of the future geodynamic regime, but it is hardly worthwhile, because the prognosis cannot be verified. However, we should take into account the effects of the modern geodynanic regime on the planet, as contrasted with the preceding Riphean-Phanerozoic regime. All attempts to reconcile presently observed phenomena that comprise the regime of our own day, with events of the geological past and to correlate in any comprehensive way the modern geological situation with past tectonomagmatic cycles are wholly frustrating. No correlation exists.

Clearly, the proposed model has a built-in cyclicity of core decomposition. At the beginning of every cycle, hydrogen must have evolved rapidly. It must later have been reduced as fast decompaction set in. Intense hydrogen degassing should then have set off a geosynclinal cycle of tectonomagmatic events on the surface. The waning stage of degassing and decompaction of the core should have resulted in the expansion of oceanic troughs. Logically, after orogeny, continents should have quiescent tectonic regimes. Tectonic activity at this stage is restricted mainly to the expanding the Earth at rifts. As we correlate the causes of geological evolution with cyclic decomposition of the Earth's core, a logical conclusion to be drawn is that geotectonic episodes should be synchronous worldwide. This observation is a truism of major cycles, the Alpine, Kimmeridgian, Hercynian, etc. However, the major episodes may also have subcycles and spasms of orogeny due to physico-mechanical properties of the crust and mantle, layer B.

Separated in time, the hydrogen degassing events, which replenish the water reservoirs of the hydrosphere, and the decompaction phenomena that are responsible for ocean expansion, should combine to give eustatic oscillations of sea level. Oscillations of this sort have caused marine transgressions and regressions over the platforms. Incrementation of planetary water resources from interior sources at the geosynclinal stage are considered responsible for transgressions over non-geosynclinal regions, whereas ocean basin expansion by deepening is thought to have triggered regressions. These interrelationships

seem to tie in with the geological realities of distinct tectonic movements in geosynclines and on platforms. Expulsion of water to the surface must have occurred mainly at the orogenic stage, as the asthenoliths rose (see Chapter VI, 2). If juvenile water were injected into subcrustal horizons from throats, it then would be clear why, as A.D. Archangelsky once noted, platform transgressions seem to lag slightly: "... maximal subsidence of [platforms] is often contemporaneous with the transition to uplift in geosynclines" (Khain 1951).

Adhering to this dictum, we may define the relationship between existing models and hypothetical geotectonic reconstructions. Evidently, our case would be overstated if we claimed that the evidence exclusively favors the expanding-Earth concept. The hypothesis of the primordially hydridic Earth provides for pulse-like episodes of expansion temporally separated from epochs of folding. On this point our hypothesis converges in its essential points with the "pulsating hypothesis" that was advanced in 1933 by the American geologist, W.H. Bucher, and subsequently elaborated by M.A. Usov and V.A. Obruchev and supported by P.N. Kropotkin (1967) and Ye.Ye. Milanovskii (1978). Without violating customary terminology, the tectonic implications of the primordially hydridic Earth can be combined with the concept of an Earth that expands "pulse-like."

Figure 31

EARTH HEAT DISTRIBUTION

(I) DURING HYDROGEN OUTGASSING
(II) DURING PLANETARY EXPANSION

6.5 The problem of the drift of lithospheric plates

Paleobotanical, paleoclimatic, and paleomagnetic data in some instances provide evidence that seems to imply a convergence of crustal blocks from widely separated localities (Meien 1969; Vakhrameev 1971; and others). These spatial restorations can hardly be explained, it would seem, without allowing for continental drift. In actual fact, the structural plan of the oceans is equally hard to explain solely on the basis of planetary expansion, because paleotectonic reconstructions suggest that, apart from the divergence of continents that we attribute to the expanding Earth, the continents have rotated through significant angles. Recognizing this relationship is tantamount to acknowledging continental drift. Thus, the author has been compelled to look for intrinsic causes for drift within the framework of his hypothesis of the primordially hydridic earth.

In this respect, it seems particularly useful to study the thermal regimes of internal planetary spheres on the basis of the new geochemical model. As

we have already shown, this model of the Earth allows for the cyclic decomposition of the hydridic core as the reason for the cyclicity of tectogenesis. Given this point, it becomes apparent that the interior geospheres of the globe were intermittently heated during concomitant hydrogen degassing of the core or cooled by decompaction of core mass as heat was absorbed. Oscillations of the internal temperature of the planet have underlain the recurrent changes in the physical states of the tectonosphere.
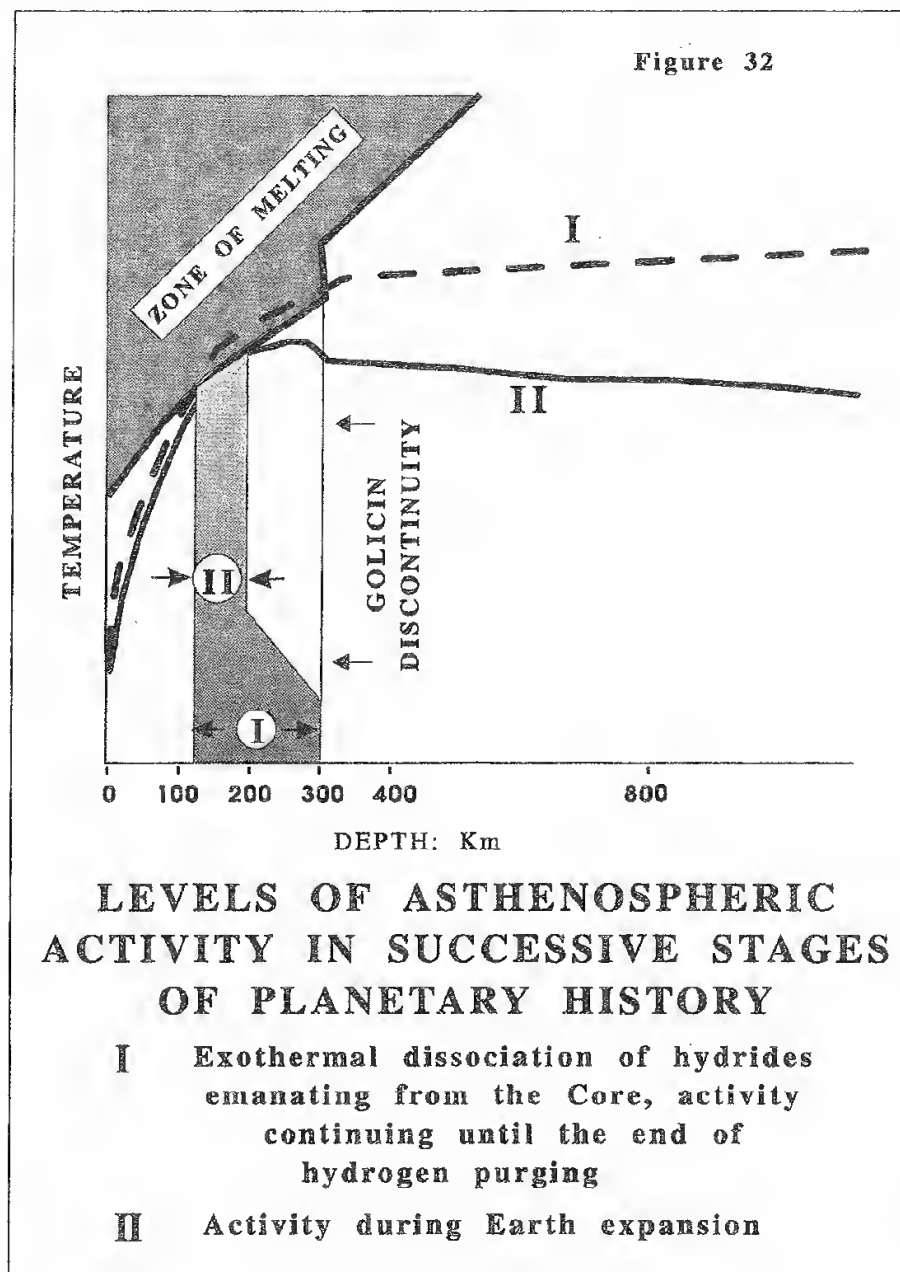
Figure 31 illustrates the principal temperature patterns within the planetary body at the stage of hydrogen degassing (I), and at the time of expansion of core mass (II). Note that we have to show a retrograde slope to the temperature curve in the mantle, as it is impossible otherwise to reconcile the heat flow values with average uranium concentrations in the planet, as defined on the basis of the magnetic separation of elements in the protoplanetary nebula. Much lower geothermal gradients below the Golitsyn discontinuity are due to the higher heat conductivities of silicides. These conductivities are almost an order of magnitude above those of the silicate and oxide minerals of the silicon-oxygen shell.

The implications posed for the silicate-oxide shell, which acts as a kind of thermal insulator for the planet, against the heating and cooling of inner geospheres, are shown in Figure 32. Even these purely qualitative plots bear witness to cardinal differences among the outer geospheres (the "tectonosphere") at various periods in geological history. When exothermal decomposition of the inner core hydrides took place and temperatures in the bowels of the Earth rose abruptly, asthenospheric thickness must have increased considerably through the softening and partial melting of the lower levels of the silicate-oxide shell. By contrast, when the core was expanding, heat was being absorbed, and temperature was declining, the asthenosphere suffered attrition, if not complete elimination.

Thus, the hypothesis of the primordially hydridic Earth and the logical implications to be drawn from it with respect to planetary evolution provide an alternative explanation for geological epochs in which fundamentally different states of the tectonosphere prevail. Throughout some periods most of the silicate-oxide shell was either soft and near melting, or it was partially melted from below. In other periods of Earth history the asthenosphere became thinner and probably laterally discontinuous. In the first case heating would have affected everything from the very bottom of the silicon-oxygen shell. In the second case, it is confined to the uppermost level of that shell. The latter is typical of the present stage in the life of our planet.

A thick and widespread asthenosphere would certainly allow for continental drift, whereas a thin and discontinuous one would greatly limit it. Our hypothesis logically allows for periods in Earth history when extensive continental drift could have occurred. However, for drift of lithospheric blocks and plates actually to happen, there needs to be some motivating force to make plates move on a thick and widespread asthenosphere. Researchers have already proposed a variety of scenarios for the driving force, including

convective flows in the mantle, planetary rotation, and various processes inside the Earth that impose a particular topographic configuration on the base of the asthenosphere. In the latter case, drifting would result from gravity-induced shedding of lithospheric blocks from uplifted welts on the mantle.

Figure 32

LEVELS OF ASTHENOSPHERIC ACTIVITY IN SUCCESSIVE STAGES OF PLANETARY HISTORY

I   Exothermal dissociation of hydrides emanating from the Core, activity continuing until the end of hydrogen purging

II   Activity during Earth expansion

Our concept treats these scenarios differently. It precludes convective flow in the mantle due to the incompatibility of the concept with known chemical discontinuities. It takes a neutral stance on the question of the contribution made by rotational forces. It actively supports the concept of possible topographic uplift at the base of the asthenosphere, because that

looks like a good explanation for horizontal lithospheric movements.

Most of the heat generated by exothermal decomposition of hydrides in the outer zone of the inner core must have migrated with the exceptionally efficient heat-transfer agent, hydrogen, into the outer geospheres, as already shown. An originally homogeneous flow of hydrogen must have been differentiated due to the exponential relationship between diffusion rate and temperature.[13] Hence, uneven heating of the inner geospheres should be maximized in zones of maximal flow of proton hydrogen; and those zones should show larger increments of expansion. This consequence of the hypothesis of the primordially hydridic Earth essentially conforms to van Bemmelen's "mega-undation" concept, which implies vast swells of the upper geospheres that would reflect a deep-seated phase-change, or mass "hypodifferentiation" in the lower mantle. This uplift would provide for gravity sliding of lithospheric blocks off the swells, "drifting" in appearance if not in fact.

The reader will have noted that these causes of drifting allow for variations in magnitude for the phenomenon that includes a regular increase from earlier to later stages in geological history, but restricts movement of lithospheric plates to the prescribed mode. From core to outer geospheres, heat is conveyed through the mantle, which acts as a heat buffer, cushioning the thermal effects in the tectonosphere. Because our hypothesis envisages incrementation of mantle volume with time through the agency of decomposition of core hydrides, the amplitudes of thermal oscillations in the tectonosphere should progressively decline. In other words, over time recurrent events of partial melting followed by freezing in the silicate-oxide layer would become more subdued.

We would be remiss to ignore the channel-growth aspect of hydrogen migration, wherein heat is transferred as the Earth expands, and the mantle gains thickness. This process was discussed (Chapter VI, 4) in connection with evolution of geosynclinal regimes. It is evident that, if diffusely migrating hydrogen had coalesced into channels as the mantle expanded, the heating and softening of the tectonosphere would, from that point on, have been restricted to tectonogenic zones, and the asthenosphere then could not have become global. Additionally, mature ocean troughs would have evolved in association with discontinuities in the asthenosphere (Chapter VIII, 2). It follows logically, then, that any discontinuity in the lateral continuation of the asthenosphere should be a restriction to lithospheric drifting.

It is self-evident that climactic drifting and planetary expansion should occur periodically over the span of geological time. Earlier in Earth's history, when the mantle was thin, drifting would be expected to have been prominent. Later in geological history, drifting would largely have given way to processes of expansion. This may account for the difference in

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[13] *The flow of hydrogen from the Earth's core must be uninterrupted, although its intensity may vary. Jets should be numerous by the time they enter the mantle (Figure 29).*

structural plans of the Pacific and Atlantic oceans. Pacific structure, being older, has had more chance to be affected by continental drift than the Atlantic Ocean, which was only created much later and under a geodynamic regime dominated by expansion. It should not be interpreted that our concept precludes drifting in Alpine time. Drifting may, in fact, have occurred; but its effects would tend to have been regional rather than global. As we have shown, Mediterranean-type seas in sectors of active Alpine orogeny have originated from recent motions caused by drifting.

Thus, the proposed hypothesis may offer an explanation for epochs of energetic drifting throughout the history of the Earth. These epochs are seen to alternate with periods of consolidation of the tectonosphere. At the same time, this hypothesis restricts the global effects of continental drifting in the later stages of planetary evolution, when processes of expansion had accelerated. Despite this limitation, which applies mainly to the Meso-Cenozoic. a relatively short period of geologic time, the hypothesis of the primordially hydridic Earth can still be viewed primarily as a mobilistic theory.

CHAPTER VII

PETROLOGICAL AND GEOCHEMICAL CONSEQUENCES OF THE HYPOTHESIS OF A PRIMORDIALLY HYDRIDIC EARTH

7.1   Formation of Earth's crust: the K-source enigma

In recent geological literature much attention has been directed toward what has been termed the potassium problem, or more precisely, the problem of the source of potassium, which arises from a discrepancy between the relatively high crustal abundance of K and its presumed lesser abundance in the Earth's mantle as deduced from chondritic or pyrolitic models. In this section of the book we intend to reveal a number of geological aspects of the K problem and new solutions to the problem.

The idea of using meteorite data to estimate averages for elements in the global makeup appeared in the last century. It was later strengthened by V.M. Goldschmidt, J.G.F. MacDonald, A.P. Vinogradov, and many other scientists, who established approximations of the comparative abundances for non-fugaceous chemical elements in chondrites and the Sun. This amounts to a material balance for the solar system, which has been accepted as true up to now. It presumes that meteorites represent fragments of an Earth-like planet.

Compared to rocks that comprise the outer geospheres of the Earth, chondrites are much less differentiated. It was this fact that seemed to justify the assumption that average chondrite elemental abundances are inherently similar to the clarkes of the Earth and other terrestrial planets. These are the basic principles of the chondritic model of the Earth and its mantle.

The Ringwood-Green pyrolitic[1] model of Earth's mantle is based on petrological data, which presupposes firstly that the outer geospheres produce large amounts of basaltic magma and retain a refractory mantle residuum ("restite"). The restite is thought to be represented by alpine-type ultramafic rocks that have been extruded upon the surface in fold belts. These rocks have been much studied. On this basis it has been concluded that the

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[1] *The word "pyrolite" is a synthesis of the initial letters of two mineral names, [PYR]oxene and [OLI]vine.*

principal composition of the mantle is a 3:1 mixture of ultramafics and basalt. This ratio with respect to six major elements, Si, Mg, Fe, Al, Ca, and Na, is in good agreement with chondrite data (Ringwood 1972). The coincidence is taken by A.Ringwood as proof of the validity of the pyrolitic model. In his later work the abundances of minor and trace elements in chondrites are also correlated with pyrolite.

Thus, the pyrolitic and chondritic theories of the mantle are thought to compare closely as to major elements and entirely as to minor and trace elements. However, the chondritic model of the mantle is contradicted by some available geochemical data on crustal and upper-mantle elemental abundances. One of these contradictions is keyed to the problem of the source of potassium for crust-forming processes and in abyssal mantle magmas.

Elemental abundance characteristics and thickness of the crust are known by now and enable estimation of depth limits from which elements may have separated within the mantle. If chondrite abundance levels are to be attributed to primary (undifferentiated) mantle, and if abundance levels in dunites represent the restite, in order to account for all the K found in the crust, it would be necessary for the element to be stripped from the entire mantle from the base of the continents to the core. If this had been the case, how would one explain the post-crustal appearence of such phenomena as the enormous trapp effusions, K-basalts, kimberlites, and other mantle differentiates with K_2O content of 1% and higher within the platforms? In this case a presumption of pervasive assimilation of crustal material is clearly unfounded. It is notable that no increase in K content as a rule is found to match changes in the concentrations of other major elements. Such parallel response is inherent and essential to the assimilation of sialic material.

Additional dramatic contradictory evidence against the chondritic model emerges when one compares terrestrial Rb, Cs, U, and some other elements with their chondrite abundances. Complete mismatches are found between the chondrites and appropriate crustal bulk resources. For example, U content in chondrites approximates only one-quarter of the crustal resource, even with total U depletion of the entire mantle.[2] Thus, to achieve conformity with the chondritic model and rationalize the abundance levels of many elements, there must be either some additional extraterrestrial source of these elements, or there must be a process of endogenic, intraplanetary, nuclear synthesis in operation. Some authors hold this very opinion, ignoring its physical absurdity.

Advocates of the pyrolitic model, on the other hand, evade the problem of crustal element abundance and try to explain away some of the many

[2] *Average concentrations of chemical elements in the crust, in chondrites, and in dunites for these calculations are taken from A.P. Vinogradov. Thickness of the crust is taken to be 37.5 km. Downward taper of blocks is taken into account to calculate depth of elemental secretion.*

anomalies of the distribution of elements in basaltic magmas. According to these authors, minor and trace element distributions in pyrolite mantle are the same as in chondrites, and hence, one may expect parity between the chondritic elements and a 1:3 mixture of basalt and dunite. However, only a few of the elements making up these rocks actually have the predicted balance. Far more of the ratios of chondrite values as compared to basalts and dunites are markedly either deficient or in excess (Table 8).[3] It is notable that groupings of elements are demonstrated by the exercise of comparison of the chondritic and crustal abundances.

TABLE 8

GROUPING OF THE MINOR AND TRACE ELEMENTS IN THE CHONDRITIC MODEL OF THE EARTH'S MANTLE

Deficient [Incoherent]	Balanced [Coherent]	Excessive	Super-excessive
K, Rb, Cs, U Th, Ba, Sr, Tl, Zr, P, Ti	Ni, Co, Cr, Mn, V, Sc	Au, Pt, Pd, Os, Ir	S, C, Hg

As the literature attests, most authors are little interested in the problem of excessive and super-excessive abundances of elements. Their attention is diverted toward explaining specific high concentrations of K, Rb, U, Th, and elemental deficiencies in basalts and other crustal rocks. Ringwood calls these elements "incoherent" in order to discriminate them from "coherent" elements, whose average values in basalts and dunites and those of chondrites are in balance and vary in conjugation with the major petrogenic elements. Enrichment of basaltic magmas in the deficient elements is explained in several ways: (1) partial melting of the mantle with most elements accumulating in the liquid phase; (2) fractional crystallization, which leads to accumulation of the deficient elements in the residual liquid phase; (3) interaction with overlying, upper-mantle components with attendant extraction of deficient elements; and (4) contamination by crustal rocks enriched in deficient elements. All of the above explanations are objectionable, due to limitations to elemental partitioning capacities or to inapplicability within whole scenarios of petrogenesis. Do the details merit discussion? Can the problem as posed be resolved at all? Probably not, because the crustal clarkes of the deficient elements are juvenile features, which could not have been produced from a chondritic mantle.

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[3] *After A.Ringwood and demonstrated by him at the XVII Vernadsky memorial readings at the Institute of Geochemistry and Analytical Chemistry, Moscow, on the 12th of May, 1975.*

Now let us consider the categories of excessive and super-excessive elements. A problem that arises here is to define the historical migratory paths of escaping platinoids, gold, sulphur, carbon, and mercury, the elements for which chondritic abundance levels are 10 to 100 times above those of common crustal and mantle rock. Kimberlites and abyssal inclusions within them of pyrope, peridotite, or pyroxenites are characterized by background levels of gold (Lutz 1975) and mercury (Saukov et al. 1972; Ozerova et al, 1976) that do not differ from clarke values of these elements for the crust. Here, however, unlike the deficiency case, the supporters of the chondritic model may invoke differentiation to impute the sequestration of these representatives of periodic law (after Mendeleev) to an inaccessible abyss of the Earth and, thusly protecting the hypothesis from substantiation and creating an illusion of validity.

Here then, in the chondritic model of the Earth, we can see that the source of potassium for crust-forming processes is but one aspect of the problem of deficient elements requiring resolution, its counterpart being the problem of the excessively abundant elements. As no universally acceptable solution has been found to now, we propose to seek it through the efficacy of comparative cosmochemistry in the solar system.

Ringwood's classification of chemical elements (deficient, balanced, excessive, and super-excessive) is accountable within the schematics of magnetic differentiation. The classifications differ according to elemental ionization potentials. What explains the differences between the separations of the elements in the magnetic field and their changing abundances with increasing distance from the Sun? A comparison of data of Table 8 with those of Figure 2 supports the hypothesis that elements of low ionization potential are mainly in the "deficient" class, while "excessive" and "superexcessive" classes include elements of enhanced and high ionization potential.

Therefore, it may be concluded that the potassium problem, and the enigmas of element groupings (deficient, balanced, excessive, and super-excessive) are created by the imputed identity in composition between meteorites and rocks of the outer geospheres of the Earth. Magnetic separation of protoplanetary matter is ignored. If magnetic separation is taken into account, the chondritic model appears absolutely unacceptable, whereas the vast store of data accumulated on meteorites loses not a single grain of significance. In fact to the contrary, it gains fresh appeal. These data can be successfully applied to estimate the primary composition of our planet that follows from the systematic magnetic separation process, which the author has discovered.

If we suppose that meteorites really do reflect the composition of planetary matter from the asteroid belt and that the slope of the locus of their major populations (Figure 2) is determined by magnetic separation, then the regular variations in elemental abundances are functions of distance from the Sun. On this basis it may be said that the K content of the primordial

Earth should exceed its concentration in meteorites by one order of magnitude. This estimate is based on the following relationship:

$$C_{(e)} = C_{(m)}/f,$$

where $C_{(e)}$ is the estimated abundance of an element in the Earth,
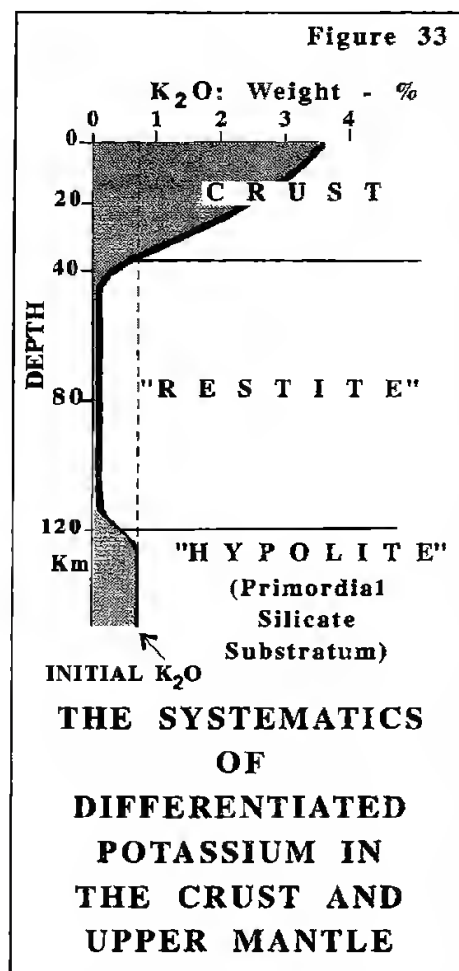$C_{(m)}$ is the known abundance of the element in meteorites, and
f is a fractionation coefficient.

The numerical value for f is determined as follows. The locus of the major populations is a straight line. An element is projected vertically to this line, according to the value of its ionization potential. The ordinate of the projection provides the quantity sought. It amounts to a ratio of primary abundance of a certain element in meteoritic matter to that in terrestrial matter. We estimate the value for the ratio, K, as 0.07-0.08. Thus, average terrestrial abundance of K is to be equal to ca 0.8 wt % as a metal or ca 0.9-1.0% as an oxide, while the abundance level of K in meteorites is about 0.06% wt. Because there is a 40% increment due to oxygen (in the outer silicate shell), average content of K within the silicate-oxide shell is, manifestly, about 0.5% as a metal or about 0.6% as an oxide. If this initial concentration for K in terrestrial matter is valid, then the constraint on a potassium source in crust-forming processes is lifted. Simultaneously, a new, non-traditional way to analyze certain petrological and geochemical problems is revealed.[4]

According to our estimate of K abundance, in order to produce a crust of 37.5 km thickness and consisting of 1 part granite and 1.5 parts basalt with an average K_2O content of 1.8 wt %,[5] it would require the extraction of all the K in the mantle down to a depth of 120 km (assuming a residual K_2O concentration of 0.05 wt-%). Consequently, according to our calculations, the K-depleted subzone of the upper mantle would have to be underlain by a mantle subzone undifferentiated with respect of K (Figure 33) and a K_2O content tending to be close to the primordial level of ca 0.6% wt-%.

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[4] *This operation should be acceptable if specific deviations of the elements from the average line can be related to redistribution of the elements within the body of the Earth, that is, to correct for error caused by inaccurate estimation of the correlative chemistries of the mafic/ ultramafic mixture in the primordial Earth. Primarily it pertains to such elements as K, Rb, U, Cs, and some others, which underwent major redistribution within the outer geospheres in the course of crust formation. This procedure is not applicable to elements representing exogenic additions, because depletion of elemental content in meteorites represents the initial abundance within the parent body. There are some reasons to believe that anomalous positions taken by Ta, Nb, Th, Ce, and P in the plot are a condition resulting from extraction of the elements from the meteorites' parent body and the concentration of these elements in differentiates that ensued. The latter are considered to have failed to "survive" interaction with the terrestrial atmosphere. This aspect is discussed in Chapter X-1.*

[5] *Clarke values for basalts and granites taken from K.Turekian and K.Wedepohl.*

Figure 33

K_2O: Weight - %

0 1 2 3 4

C R U S T

"R E S T I T E"

"H Y P O L I T E"
(Primordial
Silicate
Substratum)

INITIAL K_2O

DEPTH

THE SYSTEMATICS OF DIFFERENTIATED POTASSIUM IN THE CRUST AND UPPER MANTLE

This deduction can be checked using data on abyssal inclusions in kimberlite diatremes. The deepest-formed of these intrusions are believed to be "grospydites" (grossular-pyrope garnet, diopside, and blue kyanite) and diamondiferous eclogites. Experiment-al data on the synthesis of grossular-pyrope garnets (MacGregor 1964-1965) and diamonds (Bundy et al. 1961) attest to the formation of these minerals at pressures of no less than 3.5-4.0 GPa, the values corresponding to a depth range of 100-120 km. It is noteworthy that grospydites and dia-mondiferous eclogites are characterized by relatively enhanced concentrations of K (ca 0.75-0.85 wt %), which differ in this aspect from mantle inclusions of lesser depths (pyrope peridotites and pyroxenites, spinel lherzolites, and alpine-type ultramafics) where K con-tent does not exceed 0.10-0.15 wt-%. It should be pointed out that kimberlites are also enriched in K.[6] This phenomenon can hardly be explained as a result of assimilation of core matter, because there is virtually a total lack of indication of either dissolution or assimilation of xenogenic fragments (Lutz 1974). Most authors relate formation of kimberlites to mantle melting at depths of 150-200 km, i.e., within a zone where a primary undifferentiated substrate occurs, according to our notions. Thus, data on kimberlites and abyssal inclusions favor our theory.

The characteristics of inclusions in basalt[7] enable us to arrange basaltoid formations into the following sequence in order of increasing depth of generation: tholeiitic, high-alumina, alkaline olivine, and potassium. The sequence also reflects the increasing role of K in basaltoid melts with increasing depth of generation. Whereas this phenomenon is usually related to assimilation of crustal material, in this case an inherent relationship between generation depth and K content remains unexplained. In terms of

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[6] *Average content for 623 analyses of the rock samples from Yakutia, pure kimberlite with no inclusions, is equal to 0.79 wt %; (Ilupin & Lutz 1971).*

[7] *Kuno, 1972,"Glubinniye ksenolity...", 1975.*

our concept, increasing K content of basaltoid magmas with depth is understandable upon the removal of the "sources" from the restite zone (where only tholeiites can be produced) to the substrate zone of the primary mantle. The potassium content of this zone ranges up to 0.6 wt %, sufficient for magmas originating there to be K-enriched. Because this concept is based on a cross-section of the outer geospheres (Figure 33), a restoration of the composition of the primary undifferentiated substrate is possible.

Data on abyssal inclusions in kimberlite diatremes permit us to theorize that the mantle, from the Moho discontinuity to a depth of 120 km, is represented by peridotites (plagioclase, spinel, or garnet type, depending on the depth) containing blocks or lenses of eclogites or clinopyroxenites comprising 9-10% of the lithospheric volume. This composition is predictable from specimens of the most representative collections (Glubinniye et al. 1975). As a consequence, the mantle within a given depth range can be presented as a 1:10 (0.5:5) mixture of mafic and ultramafic rock.

Assuming the crust of 37.5 km thickness consists of 1:1.5 granite : basalt mixture, it is then possible to deduce that its primary substrate, which once comprised the external 120-km-thick geosphere and later underwent crust-forming differentiation, may be represented by a 1:2:5 mixture of granite, basalt, and ultrabafic rock, respectively. The author suggests the name, "hypolith" (abyssal stone in Greek), as an appropriate term for this combination, because it reflects the abyssal position and the undifferentiated substrate that underpins the continents today. In consonance with this syllogism is the common term, "hypothesis," which corresponds to the nature of the author's concept.

Clarkes taken from K.Turekian and K.Wedepohl are used in calculations of the chemical composition of the hypolith. They show that the main components of ultramafic rocks resemble those of spinel and pyrope peridotites, which comprise the inclusions in the kimberlites. In addition, these authors distinguished Ca-enriched granites, which are petrochemically similar to the averaged composition of siallic crystalline rocks (after R. Daly). Calculations have also revealed a similarity between the hypolith and verlite (pyroxene peridotite).

Thus, hypolith composition should not be regarded as exotic. Its normality can be seen in the following tabulation:

	SiO_2	TiO_2	Al_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	
Total Hypolith	48.2	0.7	8.0	10.4	0.2	24.8	5.5	1.5	0.6	0.1	100%
Verlite	46.5	0.7	5.9	13.3	0.3	23.6	7.7	1.2	0.6	0.2	100%

Note: Verlite average after R. Daly

Calculated normative mineral compositions (Table 9, after P. Niggli) indicate that at low pressure the hypolith can be presented as websterite-lherzolite, while abyssal facies of hypothetical mantle substrate should have a garnet-olivine pyroxenite composition.

TABLE 9 NORMAL MINERALOGY OF HYPOLITE	
SHALLOW FACIES, %	**ABYSSAL FACIES, %**
Olivine (forsterite 74%) -- 41.1	Olivine (forsterite 72%) -- 27.4
Plagioclase (anorthite 51%) -- 25.2	Clinopyroxene** -- 23.0
Enstatite -- 20.0	Enstatite -- 28.8
Diopside --- 9.6	Garnet*** -- 20.7
Leucite* -- 2.8	
Ilmenite -- 1.0	
Apatite -- 0.3	

* Or = orthoclase (as antiperthite).
** Diopside + jadeite (1:1); K-Na jadeite (1.0:3.5).
*** Grossular-almandine-pyrope (1:1:1).

7.2 Aspects of continental crust and mantle evolution

Summarized petrochemical data for various periods on all continents reveal an abrupt increase in the potassium content of metamorphic, sedimentary, and igneous rocks at the transition from Archean to Proterozoic time (Engel et al. 1974; Figure 34). The data of Engel and his co-authors bear witness that an enrichment of potassium in crustal mass proceeded as a widespread and sudden event. Appropriately, such a global geochemical phenomenon deserves to be entitled a "potassium explosion," a term in conversational use among scientists, but never encountered by the author in the scientific literature.

The specific and widespread granite-forming processes that generated the granite cover over the mafic-andesitic Archaean continental underpinnings represent a petrologic consequence of the "potassium explosion" (Markov 1962; Pavlovskii & Markov 1963; Glukhovskii & Pavlovskii 1973). The earliest known granitoids are dated ca 3.5 b.y. These are low-potassium plagioclase (primarily enderbitic) granites that are incommensurately small bodies when compared to later-formed, early-Proterozoic granites (Kuznetsov & Isokh 1969). It was in early Proterozoic time that the mature, granite-metamorphic cover became established over vast territories, a change that has been described as "...fundamental transformations of the material composition [and] potassium (microcline) granitization of earlier-formed layers" (Peive et al. 1976). Subsequent stages of the Earth's history can be seen as gradual incrementation of the continental crust (specifically, the thickness of the granite-metamorphic layer) at the expense of the melanocratic

basement (Peive et al. 1976). In the course of this long and multi-stage process of the continental growth a significant role was played by potassium metasomatism combined with lateral transport of sialic materials in surficial forms and tectonic imbrications.

Thus, questions of the source and functioning of potassium from early Proterozoic time to the present are moot. Some authors maintain that granitization conditionally occurs after processes of de-granitization at deeper crustal horizons where alkalic, "dry" rocks are transformed in "ultrametamorphism" (Ramberg 1952; Mehnert 1971; etc). In certain cases, however, granitization has transformed the deepest, already-dehyrated, crustal levels, including potassium-depleted, pyroxenitic, mafic, crystalline schists of granulite metamorphic facies. In that habitat only juvenile, subcrustal granitizing fluids are possible (Korikovskii 1964; Kuznetsov & Isokh 1969; etc). This conundrum brings many modern authors to support D.S.Korzhinsky's concept whereby juvenile, transmagmatic, alkaline fluids induce granitization (Korzhinsky, 1968). The source of alkali elements in the abyssal fluid, as well as the reasons for the sudden appearance of fluids with granitizing properties at the Archean-Proterozoic transition remain undiscovered. As we see it, these problems are explainable in terms of the hypothesis of the primordially hydridic Earth.
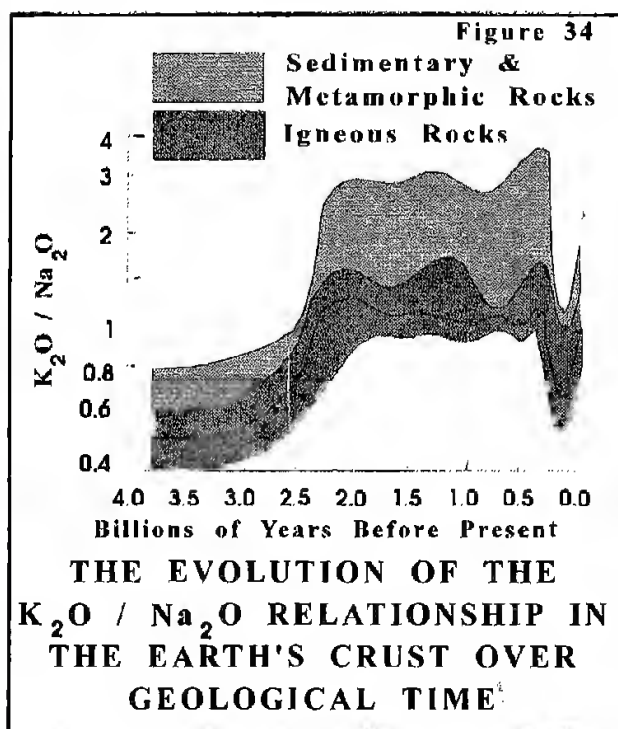

Figure 34

Sedimentary & Metamorphic Rocks

Igneous Rocks

K_2O / Na_2O

Billions of Years Before Present

THE EVOLUTION OF THE K_2O / Na_2O RELATIONSHIP IN THE EARTH'S CRUST OVER GEOLOGICAL TIME

Figure 34 illustrates the fact that, during Archean time, very small quantities of lithophilic elements eman-ated from the mantle. When it did occur, the emanation triggered a dramatic change in Earth's regime, a "potassium explosion" that marked the Archean-Proter-ozoic transition. Huge quan-tities of the lithophilic metal escaped from the mantle into the crust. The "explosion" most likely was unrelated to a high temperature regime of the planet, because the level of potassium activity in previous Archean time was the lowest, while mantle temperature was the highest in Earth history.

These facts are supported by the existence of steep, lateral and vertical geothermal gradients (Engel et al. 1974) as well as an active geodynamic background in the period (Pavlovskii 1975; Glukhovskii et al. 1977).

The cause of the K phenomenon should be sought in the evolution of the composition of the mantle. Inasmuch as potassium forms the strongest base among the petrogenetic elements, it would seem only natural to assume that its exodus is related to a change in a regime of acid-base interaction in the bowels of the Earth. This conjecture is supported by changes in fluid compositions. Granulitic Archean metamorphic activities occurred under the influence of a highly-reduced, anhydrous fluid, the composition of which must have been dominated by H_2 and CH_4. Proterozoic formations are in general characterized by amphibolitic facies. Mineral eqilibria of these facies require high partial pressure of water and carbon dioxide, in other words, completely oxidized fluid. These conclusions are based on previous thermodynamic and laboratory experimentation, which recently have been confirmed by direct analyses of fluid inclusions from the rocks themselves (Letnikov & Shkandrii, 1976). Thus, the synchrony between the first appearance of water (or other oxidation agents) in abyssal fluids and the "potassium explosion" may portend their inter-relationship.

For a better understanding of the dynamics and mechanisms of the release of alkali metals, certain peculiarities of the structure of melts in relation to the Si:O ratio have to be considered. To elucidate this relationship, Zharikov devised a "base index," where bs $= O / Z$, expressed as mol units; where O = oxygen; Z = silicon + other acid-forming metals.

Depending on the value of this O / Z ratio, a quasi-crystalline structural framework in the melt is made up of rigid Si-O tetrahedra, which is polymerized in various ways. At bs ≤ 2, the highest polymerization grade, has a tendency to form a 3-D silicon-oxygen framework. At $2 <$ bs < 3, the melts tend toward a 2-D polymerization pattern; whereas at $3<$ bs <4, the pattern tends to be linear. At bs ≥ 4, there is no polymerization in silicate melt (Zharikov 1969). When Al is present in a silicate melt, the alkali metals allow it to produce moderately stable Al-O tetrahedra. The alkali metals compensate for the relative inertness of the Al ion by forming complex compounds, such as (Al O_4)R (Appelbaum 1974).

It is only natural to think that at low bs values (bs ≤ 2) in a 3-D-polymerized melt saturated with Al-O tetrahedra, (Al-O_4)R, would have little tendency toward separation of alkalic minerals. Surprisingly, on the contrary, at higher "bs" ratios and lower polymerization grades, alkalis are easily released. It may be imagined that at $3<$ bs <4 the chains of polymer in a melt are more likely to break at their Al-O links, because these are less resilient than Si-O members (Epelbaum 1974). In unpolymerized melts (at bs ≥ 4) complexes of (Al O_4)R act as weak members, thus inducing increased fugacity of alkali and alumina.

Consequently, the hypothetical existence of a close relationship between the activity of oxygen and alkalic is confirmed by consideration

of the structural peculiarities of silicate melts. These affirm the possible release of alkali metals at a sufficiently high oxygen concentration level. Beyond this level, destruction begins to affect the 3-D, quasi-crystalline, Si-O framework of melts. As we see it, this behavior is consistent with an outpouring of K as a "potassium explosion" and, perhaps, the cause of the phenomenon.

As for hydrogen, its part in the "potassium explosion" is not restricted to being a heat carrier. The energy of H-O bond is sufficiently above that of the K-O and Na-O pairs to be equal to that of Ca-O and Mg-O, although lower than that of the Al-O and Si-O pairs. Thus, the alkali-oxygen bonds are the most favorable to allow proton emplacement (Zharikov 1969). Therefore, the role of hydrogen, where it is present in the mantle, in the systematics of our concept, is first of all to stimulate the release of alkali. Then, with sufficiently high oxygen activity in mantle melts, hydrogen-bearing fluids absorb hydroxyl groups by interaction between the oxygen anion and a proton. The effect on the electrostatic bonds that bind hydroxyl groups with cations may be to launch them, especially base cations, as free radical groupings, R-OH (Zharikov 1969). The stepwisc manner in which basic oxides dissociate is coupled to their electrostatic interaction $(R_2O \iff RO^- + R^+, RO^- \iff R^+ + O^{2-})$, which may result in concomitant motion of RO groups and ionized hydrogen. These are eqivalent to transporting an alkali metal in the form of R-OH.

V.A.Zharikov's idea on concomitant transport of alkali by streams of hydrogen (as R-OH) is considered promising, because it suggests an explanation for the coincidence of the "potassium explosion" and the first appearence of water in the makeup of abyssal fluids according to the schematics

$$ROH \rightarrow 1/2 R_2O + 1/2 H_2O.$$
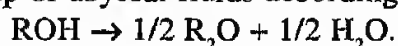
This is as much as to say that formation of granite may indeed be related to aqueous amphibolite metamorphic facies. The process of water generation, as we understand it, is a consequence of magma generation under the influence of hydrogen-containing fluids. In this relationship it is relevant to recall V.I. Vernadsky's dictum:"...magma is a birthplace of water" (Vernadskii 1960).

Evidently, a traditional approach in which the mantle is treated as an entirely silicate-oxidic geosphere with an unchanging base index, hardly explains the 2.0-2.5 b.y. delay of the "potassium explosion" from the birth of the Earth through the entire Archean era. In that era the upper mantle was intensely hot and may indeed have experienced convective mixing. According to the hypothesis of a primordially hydridic Earth, a base index increase is proposed for the exterior silicate geosphere along with an appropriate decrease in the grade of polymerization. The processes developed in conjunction with enhanced levels of oxygen activity and concentration. When hydrogen-bearing fluids were available, release of alkali from the mantle as R-OH groups was possible; and it was this factor that caused the "potassium explosion" and the vast progeneration of water-laden amphibolite metamorphic facies from granulite facies.

The evidence from geological observation provides eloquent testimony to the uneven growth rates of the continents (Peive et al. 1976). More than one-half of modern continental area had already been formed in Proterozoic time. The most intense superventions of granite formation in Earth's history characterized the Proterozoic and contrast strongly with the relatively attenuated levels of activity in subsequent eras. Notwithstanding the attentuation, younger fold belts tend to have greater thicknesses of newly-formed crust in general and of granitic members in particular than older crust. Let us consider the factors that regulate the rate at which granite crust is formed in keeping with the principles of the primordially hydridic Earth hypothesis. To do this necessitates estimation of possible scales of planetary expansion and the attendant changes in the force of gravity.

We relate the ocean-forming process to the general expansion of the planet. Consequently, the areal extent of oceanic crust may be used as a first approximation of the probable scale, as well as of the rate, of planetary expansion. A comparison of areal expanse of oceanic vs. continental crust shows that a 2.5-fold increase in the Earth's surface may be attributed to ocean-forming processes. The phenomenon is reliably dated to a start in the late Paleozoic and continuation with maximal activity in Mesozoic and Cenozoic times. It is, therefore, relatively "young." Most probably, the Pacific Ocean is an exception, because its peripheral structural features do not preclude initial growth in early Precambrian time (Pushcharovsky 1972; Muratov 1971; Khain 1971; Kropotkin 1971).

Simultaneously with the development of oceanic depressions, and earlier as well, geosynclinal trough formation began, and sediments were deposited on the ocean-type crust in the troughs. We are inclined to relate the origin of these troughs to the expansion of the planet. Analogous (or, perhaps, merely similar) structures can be traced back to early Proterozoic time, as shown by the Timiskaming "furrows" on the Canadian shield (Markov 1962). However, any quantitative evaluation of the possible scale of planetary expansion is quite difficult in the case of such structures, because of tectonic imbrication, which occurred in the final stages of their evolution. It may be conditionally adduced that planetary expansion, which was expressed by the formation of geosynclinal troughs, led to about 20% growth of the surface area of the Earth.

Thus, we estimate the total surface-area increase as threefold. The correlative increment of the initial radius of the Earth is 1.73 times; and the increase in volume is about five-fold. Metal hydrides may undergo 8-fold compression at super-high pressures; consequently, repetitive expansion of the primordially hydridic Earth is feasible in the course of geologic evolution by their decompaction.

The Earth's expansion, as estimated by the rate of growth of oceans, evidently accelerated with time. The total area of the "young" oceans (the Atlantic, Indian, and Arctic), approximately equals that of the Pacific.

Proportional relationships between older and younger (Mesozoic-Cenozoic) segments of this basin are elusive due to extreme volcanic activity, which may very well have buried rocks of Paleozoic, and perhaps, greater age. Such burial is a distinct possibility throughout the western Pacific, where no magnetic-stripe anomalies exist and volcanism is active. If we take the age of the Western Pacific to be pre-Mesozoic, and the expansion of the Earth in the form of geosynclinal troughs as taking place mainly in that same period, then it is possible to show that the surface incrementation since late Paleozoic time approximates the incrementation during the entire preceding span of Earth history. It is evident from Figure 35 that an exponential trend expresses this accelerated expansion. Our deliberations as to rate and scale of planetary expansion, while only approximations and subject to correction in future, cannot be considered illegitimate, because the principle of Earth expansion is our only concern.

Figure 35

THE GRADIENT OF EARTH
EXPANSION vs. CHANGE
IN THE FORCE OF GRAVITY
THROUGH GEOLOGICAL TIME
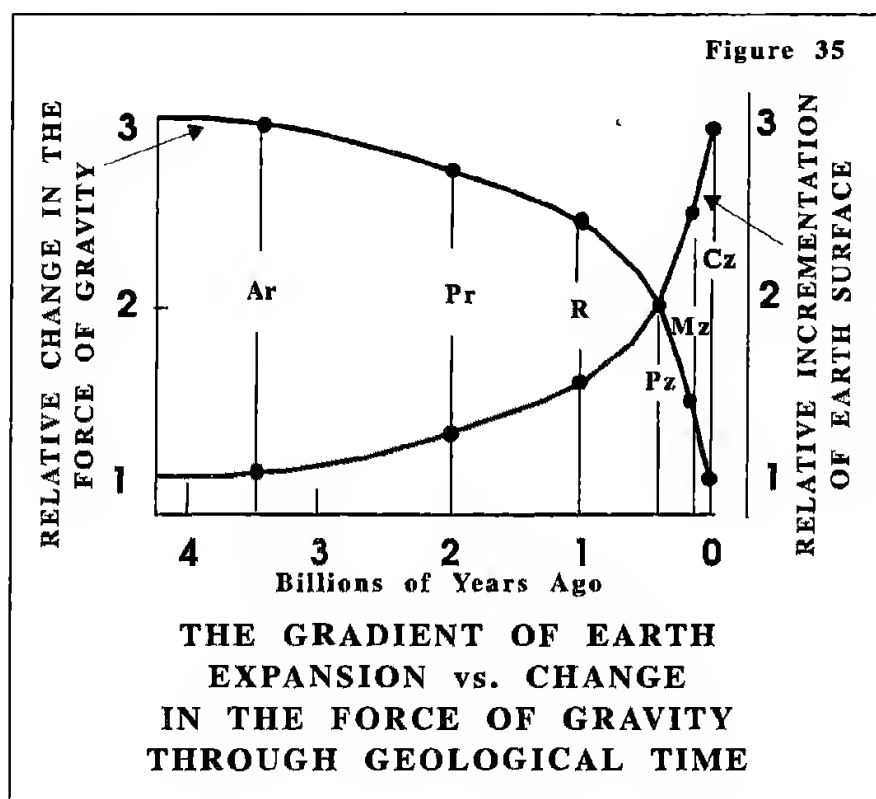
Earth expansion implies a decrease in gravitational force inversely proportional to the square of the radius of the planet. Consequently, changes in gravity may be illustrated graphically as mirror reflections of the curve representing the growth of Earth's surface area (Figure 35). From such a plot, provided a scale and a rate of the planetary expansion are known, it is possible to calculate values of the force of gravity along with appropriate estimations of pressure gradients in the mantle for various times in geological history.

Earlier we established a composition for the hypolith, the primary undifferentiated mantle matter, as a 1:2:5 mixture of granite, basalt, and ultramafic rock, respectively. The normal petrology of hypolith under the conditions of the grospydite and diamond-pyrope facies represents pressures of 3.5-4.0 GPa. The petrological makeup is olivine, orthopyroxene, clinopyroxene, and grossular-almandine-pyrope garnet in approximately equal quantities. Potassium is "forced" into monoclinic pyroxene, because inclusions from the deepest provenance, the diamondiferous eclogites in kimberlites and pyroxenes (especially those associated with diamonds) usually display enhanced potassium content (Marakushev 1972; Dobretsov et al. 1971), which is controlled by their crystalline structure (Sobolev et al. 1971). It has been shown experimentally that potassium does not enter synthetic pyroxenes at pressures up to 3 GPa (Shimizu 1971). But in the pressure range of 4-10 GPa the K_2O level may reach 0.3 wt %. This percentage reveals the isomorphic properties of the relatively large K-ion that enters pyroxene lattices at high pressure. Its behavior is facilitated by the relative ease of compressibility of the K atom compared to other petrogenetic elements. This physical property equalizes differences in atomic radii and enhances isomorphism with increasing pressure. Theoretically, the formation of K-pyroxene under high pressure is predictable (Dobretsov et al. 1971).

TABLE 10

VALUES FOR THE FORCE OF GRAVITY AND THE DEPTH OF THE 10 GPa ISOBAR AT VARIOUS TIMES IN EARTH HISTORY

ERA	AGE ybp	"g" RATIO*	10 GPa ISOBAR Depth: Km
ARCHEAN	3.5	3.0	100
PROTEROZOIC	2.0	2.75	110
RIPHEAN**	1.0	2.5	120
PALEOZOIC	0.4	2.0	150
MESOZOIC	0.15	1.5	200
CENOZOIC	Present	1.0	300

* *"g" ratio = g for era / g for Cenozoic*
** *Riphean is approximate equivalent of Sinian, Beltian, or Eocambrian. Density average for crust + mantle is 3.33 g/cm³*

Evolution of hypolith mineralogy can be deduced from available experimental data to occur at the significantly higher pressures of 10 GPa and above, which are clearly beyond the grospydite and diamond-pyrope facies. Phase transfer studies have shown that at pressure of about 10 GPa a transfer occurs from rhombic and monoclinic pyroxenes into new phases (Ringwood & Green 1972; Ringwood & Major 1968, 1971). These phases

produce a garnet-type structure, as follows:

The $CaSiO_3$ component forms a solid solution in grossular as $Ca_3(CaSi)Si_3O_{12}$.

Similarly, the $MgSiO_3$ component can be treated as a $Mg_3(MgSi)Si_3O_{12}$ component disolved in pyrope.

These transformations require that some of the Si atoms increase their coordination number from 4 to 6.

Sodium, as the jadeite component of pyroxene, enters garnet according to the following schematics: CaAl <=> NaSi or CaAl <=> NaTi..

This has all been substantiated experimentally (Ringwood & Major 1971) as well as by analysis of natural abyssal inclusions of diamond-associated garnets from kimberlite diatremes (Sobolev et al. 1971). At pressures of about 10 GPa, olivine containing 15-20 mol-% fayalite transforms into spinel (Akimoto 1975). These data suggest that spinel and garnet may be dominant minerals in the hypolith at depths where the pressure exceeds 10 GPa. At higher levels and lesser pressures pyroxene and olivine should be dominant.

The U admixture of minerals in abyssal rocks displays a regular increase in the isomorphism of crystalline lattices of the olivine-orthopyroxene-clinopyroxene-spinel-garnet series (Akimov et al. 1968).

It is also known from experiments that the grossular component increasingly dissolves in pyrope at pressures of 3.5-4 GPa and higher. These super-abyssal, orange-colored garnets are found as xenocrysts in alkaline basaltic diatremes. Furthermore, at high pressures (for which there are data available up to 4.5 GPa) Ca-Si pairs in the grossular component ($Ca_3Al_2Si_3O_{12}$) are replaced by Na and P. The higher the pressure, the greater the replacement that results in the formation of a solid mineral solution, $Na_3Al_2P_3O_{12}$, in the garnet matrix (Thompson 1975).

These facts explicitly indicate the growth of the isomorphic capacity of garnet with pressure, thus giving a firm basis for anticipating the reversibility of the process. Following from the aforementioned data on K behaviour, the general statement would seem justified that at pressures of 4-5 GPa and higher, crystalline lattices of rock-forming minerals gain an ability to effect the isomorphic capture of certain lithophilic elements, and that this ability increases with pressure. It appears most likely that a critical level for the isomorphic transformation of crystalline lattices is passed at pressures of ca 10 GPa, where the pyroxene-garnet and olivine-spinel transformations take place.

Now let us consider these data in terms of the expanding Earth concept, which entails a decrease in the terrestrial gravitational force and a depth increase for the 10 GPa isobar (hereinafter referred to as "isobar-10" to reflect the author's belief that this particular pressure level deserves a special name). The Earth expansion scale advanced here (Table 10) shows that garnetite dominates mantle rock compositions. Domination in this manner

was the case, for example, at 100 km depth and deeper, during early geological history. In the course of planetary evolution as the depth of isobar-10 increased, the spinel-garnet component was transformed into a mixture of pyroxene and olivine. We propose to retain the term "pyrolite" for this particular mixture. The term was originally introduced by Ringwood and Green and is now widely applied to undifferentiated mantle. Pyrolite, as we use the term, is the undifferentiated primary mantle substance, its composition differing in essence from Ringwood and Green's 1:3 basalt:ultramafic mixture. We regard pyrolite as a 1:2:5 mixture of granite, basalt, and ultramafic rock, respectively.

Transformation of spinel-garnet into pyrolite should be accompanied by a "lattice purging" of a number of elements (including K, U, and other lithophiles). The "purging" is made possible by decreased isomorphic capacity of the crystalline lattices of olivine and the pyroxenes compared to the garnets and spinels. The "purged" lithophilic elements then exist in a geochemically unstable state that leaves them especially susceptible to mobilization. Here, in all probability are the sources of elements for the abyssal intratelluric fluids that cause granitization and emplacement of granites in upper horizons of the crust.

Indications of the decomposition of the primary garnetite mantle are to be sought firstly in abyssal inclusions from kimberlite bodies. In this respect any regularly-oriented mineral intergrowths that could be classified as residual after decomposition of solid solutions are of special interest. First to be mentioned is the Ringwood and Lovering (1970) discovery in diamondiferous diatremes of diopside-ilmenite aggregates that had been transformed into homogeneous garnet at high pressure. Oriented intergrowths of diopside in garnet have been considered by some authors (Ringwood & Major 1968) as decomposition structures of solid solutions. They render the opinion that the data probably "...indicate past existence of garnet-pyroxene solid solutions in nature."

If one defines the composition of restite as 0.5:5.0 basalt:ultramafic rock mixture, then possible thickness of the crust composed of one part granite and 1.5 parts of basalt may be estimated if we take into consideration depth adjustments for isobar-10 (Figure 36). However, crustal stretching in the initial stages of geosynclinal trough formation, that is to say, at the "oceanic" stage, makes this estimation difficult. In addition, thickened crust cannot be preserved for any geologically long period, because the isostatic emergence of blocks of increased crustal thickness leads to high relief, which is easily destroyed by erosion. As a result, the lateral redistribution of crustal material and the averaging of crustal thickness ultimately prevail.

Notwithstanding this result, we know that fold belts on continents characteristically tend to have greater crustal thickness than is found below old platforms. Younger belts, furthermore, have thicker crust than the youngest structures within them. This regularity, in terms of our hypothesis of an expanding Earth, is understandable as a function of the gradual decay of the garnetite mantle and increasing depth of the isobar-10.
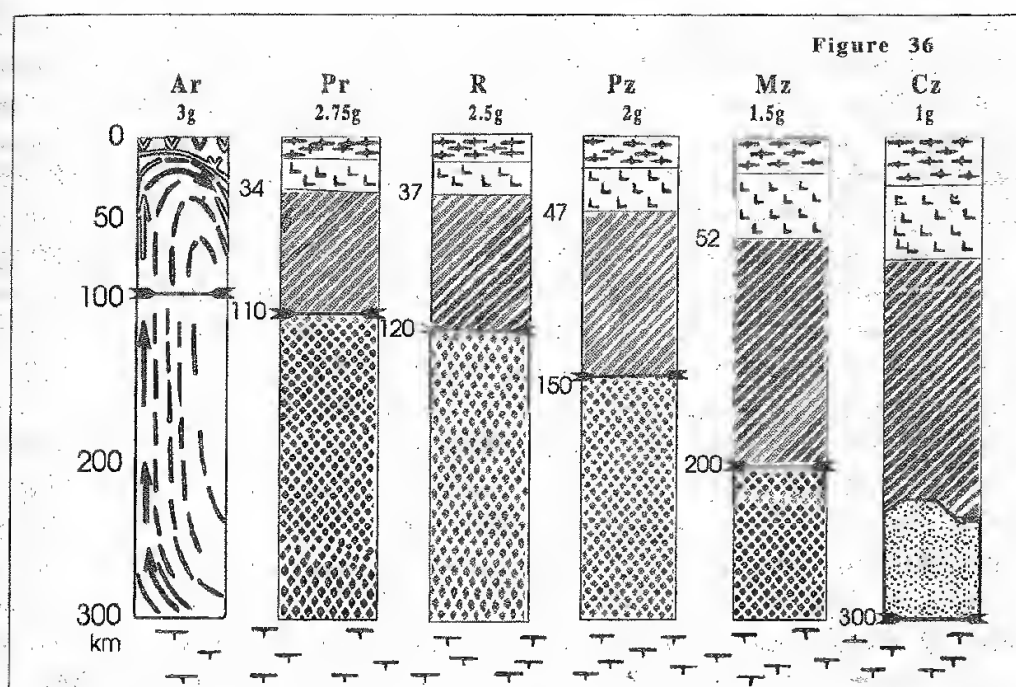
Figure 36

CHARACTERISTICS OF CRUST AND MANTLE EVOLUTION DURING MULTICYCLICAL GEOSYNCLINE DEVELOPMENT

Using the Standard Time Divisions and their respective
Gravitational Levels as Given in Figure 35

1. *Primordial Archean basaltic crust*

2. *Late Archean mantle – a silicate-oxide shell in a formative stage due to release of oxygen from deeper levels of the planet*

3. *Doubled crust – Proterozoic and Phanerozoic combined*

4. *Restite – mantle layers deficient in lithophile elements*

5. *Abyssal mantle: spinel-garnet and garnetites*

6. *Pyrolite (pyroxene-olivine) abyssal mantle – the presence of pyrolite in the Cenozoic succession represents incompletely-formed crust in the Alpine geosynclinal belt*

7. *Isobar 10 GPa*

8. *The "C" layer of the mantle – metals*

It seems quite plausible that within Alpine folded zones the crust-forming process is in progress today with concurrent expurgation of lithophilic elements from the mantle. This progression is indicated by the incompleteness in many magmatic series and the absence of batholith-scale alaskite bodies, which are inherently products of the post-orogenic stage. Intrusion of such alaskite plutonic bodies is accompanied, as a rule, by areal sialic volcanism in near-surface intrusive zones (Larin 1967). Volcanic series of this type are prominent in Cenozoic orogenic belts. Vast chambers of liquid magma have been discovered at shallow depth in these belts (e.g., Armenia) by geophysical methods. Its presence warrants the conclusion that growth in the granitic geosphere is taking place.

Thus, the "potassium explosion" that opened an era of granite formation at the chronologic border of Archean and Proterozoic time may be attributed to a change in the sialic-alkalic regime of the upper mantle induced by an increase in the concentration and activity of oxygen. Further input of lithophilic elements into the intratelluric fluid, as we see it, has followed from the formation of a pyrolite zone in the upper mantle in the course of destruction of primary garnetite accompanied by an appropriate depth increase of isobar-10.

It is cogent now to examine the metallogeny that should follow from the evolution of crust and mantle according to our model. A large group of rare elements (Li, Rb, Cs, Be, Sr, Ti, Zr, Nb, and Ta) display explicitly lithophilic geochemical behavior. In their major occurrences these elements tend to associate with alaskite, sub-alkalic granite, and metasomatites, which usually are enriched in alkali metals (Solodov 1977). This close geochemical relationship between rare lithophilic and alkali metals enables us to advocate the idea that they have a single abyssal source. From this background we propose to discuss the conditions for the deposition of ores of these elements.

Chronologically, lithophilic and rare-metal mineralization are characterized by a significant and distinct bimodal statistical distribution. Two major stages of ore formation can be identified with respect to known metal reserves. The first stage took place in Proterozoic time, in synchrony with the "potassium explosion." The second stage occurred in Phanerozoic time, starting in the late Paleozoic and reaching its culmination in Mesozoic time. Second-stage mineral deposits tend to be located in early-formed blocks on old platforms and Precambrian median masses (Solodov 1977).

In accordance with our concept, the juvenile source for the rare lithophilic and alkaline elements may be ascribed to the "pyrolite mantle layer," the primary, yet-undifferentiated portion of the mantle, the hypolith in other words, overlying isobar-10. Expurged metals from the pyrolite are flushed out by abyssal intratelluric fluids. At abyssal levels these fluids have the characteristics of hydrogen produced by core degasification. Perhaps, "flotation" is another term that could be used here. The word is used in metallurgical technology for processes of extraction and upward transportation of mobile

elements. The procedure fits the hypothetical natural phenomenon in essence.

In any case, the mode of deposition of lithophilic and rare-metal ore deposits at any particular stage is a function of the thickness of the available pyrolite layer at the time of extraction of mobile elements by intratelluric fluids. Pyrolite thickness, as previously explained, is related to the stage of tectonic and magmatic activities. After the rare and petrogenetic elements are purged or floated out, the pyrolite is transformed to restite. A new stage of ore deposition in the same crustal block may then be started only after a further spasm of Earth expansion, creation of new pyrolite masses, and the destruction of garnetite.

With this sequence in mind the intensification of metallogenic activity in early Proterozoic time is readily understandable as the effect of an enormous mass of mantle, from 100-110 km depth, being subjected to purging or flotation. This quantity of mantle compares with the amount reworked in Paleozoic-Mesozoic time. It implies an unprecedented episode of granite formation in Proterozoic time. The author believes that unique deposits of rare-metal pegmatites, such as those at Bernic Lake, Manitoba, Canada also belong in this age group.

Earlier it was shown (Figure 35) that Earth's expansion accelerated through time. In middle Proterozoic, Riphean, and early Phanerozoic times, however, expansion was reduced along with the pyrolite layer. This period of reduced expansion correlates with the great interval of time when there was reduced deposition of lithophilic rare metals. Expansion of the Earth was much accelerated starting in late Paleozoic time (Figure 35), especially in Mesozoic and Cenozoic times. Concomitantly, pyrolite mass was created as garnetite was destroyed and lithophilic and rare elements were extracted and diverted into ore deposits (Figure 37). Realization of these potentials confronts us with stark differences in the history of segments of the crust that are involved in continuously recurring geosyncline development and shield blocks of early consolidation. Within the latter, tectonic and magmatic activities terminated in Proterozoic or Riphean times followed later by the deposition of metal ores, often after a period of prolonged tectonic inactivity.

In terms of our concept, tectonism and magmatism are taken as results of degasification of inner geospheres. Resurgence of tectonism and magmatism coincide with escape of intratelluric fluid. The opposite, tectonic quiescence, signifies the absence of juvenile fluid escape. Terranes characterized by recurrent, intense tectonism and magmatism have been subject to recurrent "purging" of the underlying mantle by juvenile fluids.

Figure 37

MANTLE CHARACTER
DURING EVOLUTION OF
THE ANCIENT PLATFORMS

Legend as in Figure 36
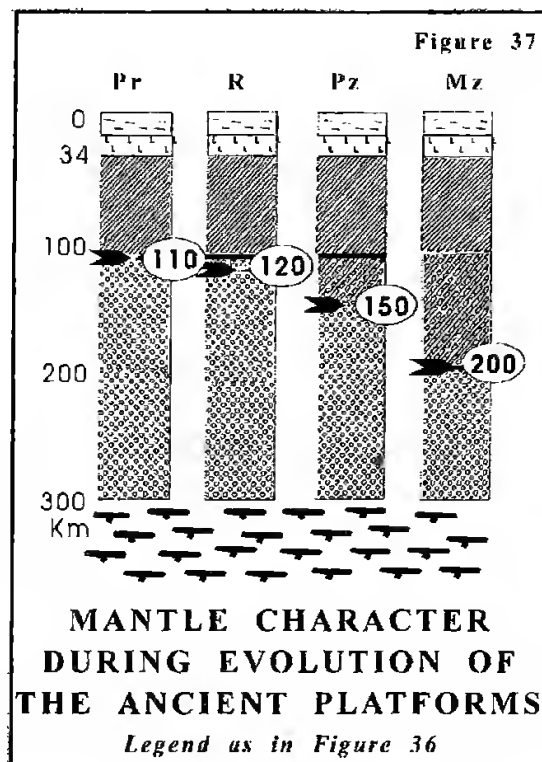
Purging, then, is the process by which pyrolite is transformed episodically into restite. Older terranes that have remained tectonically inactive for long periods, have experienced no juvenile fluid movements, and exhibit entirely different modes of tectonic and magmatic response. They experience a gradual growth of thickness of the pyrolite layer with time. Under old platforms the pyrolite may have reached 90 km thickness in Mesozoic times, while under young platforms of Riphean basement, thickness could have been as great as 80 km (Figure 37). A thick pyrolite layer of this sort in the mantle should contain lithophilic rare-metals (metals unbound in lattices of olivine and pyroxenes). This implies a larger ore potential for crustal terranes of early consolidation, as opposed to terranes linked to successive stages of geosynclinal evolution. Within such crustal terranes, juvenile mantle concentrations of metals are expressed as enhanced geochemical backgrounds, which have been deposited intermittently in one or another tectonic or magmatic cycle.

Consequently, a renewal of tectonic and magmatic activities within regions that remained inactive will necessarily be accompanied by anomalous ore deposits as the abyssal fluid flux yields "floated" or "purged" trace metal burdens that have been extracted from a thick pyrolite layer. It is most likely that the same factors ensure a well-expressed alkalic magmatism within activated regions of platforms.

Thus, in keeping with our concept, the scale of lithophilic rare-metal mineralization is dependant on the duration of the tectonic quiescence period that preceded activation and ore generation. The older the ore-hosting structure and the younger the ore, the higher the ore potential of the activated zone. This conclusion is useful for estimation of the potential for the presence of lithophilic rare-metal mineralization in a Phanerozoic structure.

However, it is necessary to take into account the acceleration of Earth expansion during the second half of Phanerozoic and the subsequent uneven growth rate of the pyrolite layer (Figure 37). These factors imply that ore potential is mainly determined by the age of tectono-magmatic

activity. The younger the ore, the more important it is that its host terrane shall have experienced a lengthy period of tectonic inactivity preceding ore deposition.

Many authors emphasize a special metallogenic significance of terranes of tectono-magmatic activity within older structures and blocks that have long remained inactive. These are "regeneration zones" (in the terminology of V.I. Smirnov & V.Yc. Khain), "revival zones" (as expressed by M.S.Nagibina), "zones of diva" (after Chen Goda et al.), "zones of teleorogenic magmatism" (after L.I. Krasnii). "Autonomous activation zones" is a recent appellation used in the publications of Shcheglov, which have attracted much attention to the problem (Shcheglov 1968, 1971). As we see it, increased productivity of these regions, especially with respect to rare, lithophilic elements, results from the buildup of the pyrolite layer in the upper mantle. Its thickening is related to the Earth's expansion, decreasing gravitational force and pressure gradient, and transformation of spinel garnetite into olivine pyroxenite (pyrolite). This transformation is accompanied by the flushing out, or "purging," of isomorphic admixtures of chemical elements, thus allowing them to be expelled, or "floated" away by ambient intratelluric fluids, which, thus, are essential elements of the ore-forming process.

Now, having considered the evolution of the crust and upper mantle below continents in terms of the hypothesis of the primordially hydridic Earth, we can understand the intrinsic factors that govern the distribution in space and time of lithophilic and rare-metal mineralization and form an opinion as to methods of prospecting for rare metal deposits on old platforms and Precambrian medial terranes. Prospecting theory is backed up with vast amounts of empirical technology (Solodov 1977). Consequently, prospecting within old platforms is aimed at the following targets: (1) mineralization localized within the crystalline basement in rocks of early Proterozoic age (contemporaneous with the "potassium explosion"), or (2) younger (late Paleozoic or Mesozoic) mineralization hosted by the basement and/or within the platform cover, and related to zones of tectono-magmatic activation.

The medial terranes are the most promising for younger mineralization, however, as they are usually overlain by sediments. Thus, for the purpose of prognosticating metallogeny, it is very important to understand the criteria and to distinguish the sedimentary covers of medial terranes from the sedimentary formations of geosynclines and the orogenic zones of fold belts (Muratov 1971).

An example of a most promising region for lithophilic rare-metals is the Aldan shield. Contained within this terrane, relics of the "lunar" stage of the Earth's history (Glukhovskii & Pavlovskii 1973) provide evidence for extremely early shield lithification and intense activity in Mesozoic time. The activity was related to superimposition of the Mongol-Okhotsky fold belt.

7.3 Trapp magmatism on platforms

Plateau basalt effusions, "trapp," belong to a category of grandiose phenomena that have played a key role in Earth history. Any concept

purporting to explain the global panoply of geologic events must include a consideration of their origins and mechanisms of their emplacement. The fundamental characteristics of plateau basalts are listed below.

Trapps are recognized chronologically to have occurred since Proterozoic time. They are found exclusively within old platforms. However, it was not until late Paleozoic time that the massive trapp effusions started. Later, in Mesozoic time, they attained continental scales. These were the Permo-Triassic plateau basalts of the East Siberian Platform (Tungusskaya syncline), the Triassic-Jurassic dolerites and basalts of the Karroo basin (South Africa), the late Triassic effusions of the Parana syncline (South America), the Jurassic dolerites of the Island of Tasmania and Antarctica (1 600 km width of cover in Queen Victoria Land) and, most recently, the late Cretaceous and Paleocene Deccan plateau basalts (India).

Morphologically, trapp formation is relatively simple, being represented by extruded, horizontally-oriented blankets in thicknesses of several km, or by sills and stratified intrusive bodies with total thickness of several hundred m. For example, within the Karroo syncline the exposed area of stratified dolerite intrusives exceeds by many times the area covered by lavas. On this basis it may be deduced that volumes of intrusive components of trapp formation are not less, and in fact, may exceed the effusive counterparts. Relatively flat synforms are the characteristic structures of plateau basalt terranes .
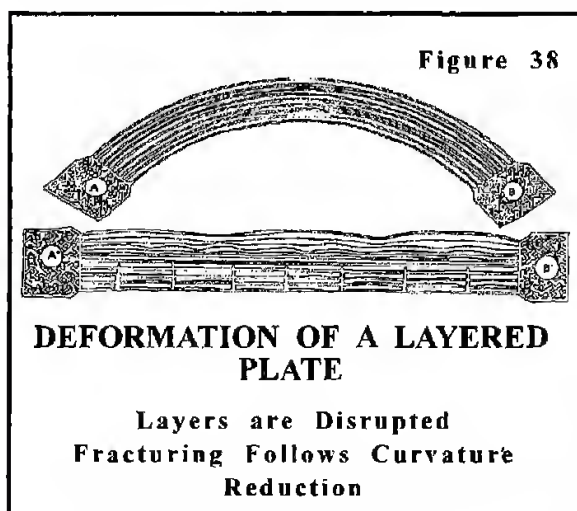
With respect to mineralogical and petrological specifics, the gabbro and gabbro-dolerites of the intrusive bodies are characterized by either total absence or only minor amounts of hydrated minerals (biotite and hornblende). Low-grade, post-magmatic alteration is inherent in these rocks. Available evidence imputes only minor water content to trapp magmas. Moreover, native iron and moissanite (SiC) are found in trapps and indicate a highly reducing fluid environment during crystallization (Goryainov 1976). A reducing environment in trapp rock is corroborated by hydrogen in the gas phase of fluid inclusions (Voitov et al. 1971).

A major problem that arises in consideration of the geochemistry of plateau basalts is exemplified by the Jurassic dolerites (Tasmania and Antarctics), where the average primary $^{87}Sr/^{86}Sr$ ratio is 0.712 and K, Rb, U, and Th are enriched compared to oceanic tholeiites. These characteristics resemble sialic crust more than mantle derivatives (Faure & Powell, 1974). Because traditional interpretation precludes the existence of any vast parent reservoir enriched in radiogenic Sr and other lithophilic elements (K, U, Th) in the upper mantle, one is forced to accept an oceanic tholeiite composition as the original makeup. That leaves the aforementioned geochemical specifics to be explained either as the result of contamination and assimilation (involving a 10-30% uptake of sialic material), or as presumed selective diffusion of certain elements into magma (Compston et al. 1968). In this latter case, an intransigent

problem presents itself in the perfect homogeneity of the trapps mixture. This is manifest in the uniformity of trapp mineralogy and element content (such as the $^{87}Sr/^{86}Sr$ ratio). Naturally, we refer to areas that have remained free of differential recrystallization and other influences of post-magmatic alteration.

Lastly, the geodynamic background of trapp-forming processes is characterized by an absence of discernible tectonic activity. This fact has led some authors to consider plateau basalts as examples of autonomous magmatism unrelated to tectonics.

Let us now consider a solution to the problem of trapp origin in the light of the hypothesis of the primordially hydridic Earth. The initiation of plateau basalt effusions on a massive scale coincided chronologically with the acceleration of ocean-forming processes, and, thus, must be related to Earth's expansion. Old platforms with localized plateau basalts represent the most stable parts of continents. Beneath them, the asthenosphere is frequently absent. The most likely characteristics for deformations that occur on a rigid, loaded arc of a sphere in the course of unbending (flattening) it, is precisely predictable from case histories of the destruction of bearing structures (Figure 38). This observation makes it possible to establish in principle the nature of different kinds of faults that occur in upper and lower horizons of the external geosphere during expansion of the planet. On the one hand, tensional strains in lower horizons will induce vertical tectonic ruptures (zones of tectonic weakness). These will penetrate upward one-third to one-half way through the silicate-oxide shell. On the other hand, as the inner surface of the shell is shorter than the outer one, a decrease in external curvature may trigger horizontally-oriented, stress-release fractures resembling desquamation in the upper levels of the shell (Figure 38).

Figure 38

DEFORMATION OF A LAYERED PLATE

Layers are Disrupted
Fracturing Follows Curvature
Reduction

In terms of our concept, the uneventful tectonic regimes associated with trapp formation preclude anticipating that the high levels of heat conducted from the Earth's interior by effluent hydrogen could have provided the energy for magma generation. Had such effluence existed, it would have induced tectonic activity (Figure 18). Nevertheless, the presence of hydrogen in trapps does indi-cate the existence of some sort of flow of the gas, albeit perhaps in weak and dispersed streams.

Even a minor admixture of hydrogen in a metal brings about a dramatic change in its physical properties. As earlier shown, under conditions of high

pressure admixcd hydrogen may result in grcatly elevated plasticity of the metal. Because of this property, the consequence of tectonic fracturing in the footwall of the silicate-oxidic shell is that C-layer metals become hydrogen-plasticized, whence they become susceptible to being injected into the shell as wedges.

TRAPPS

Figure 39

CRUST

ZONE OF
MAGMA
GENERATION

HYPOLITE | RESTITE

MANTLE
LAYER "B"

THE METALLIC "C" LAYER OF THE MANTLE

A MODEL FOR THE CREATION OF
PLATEAU BASALTS [TRAPPS]
BASED ON THE CONCEPT OF THE
PRIMORDIAL HYDRIDIC EARTH
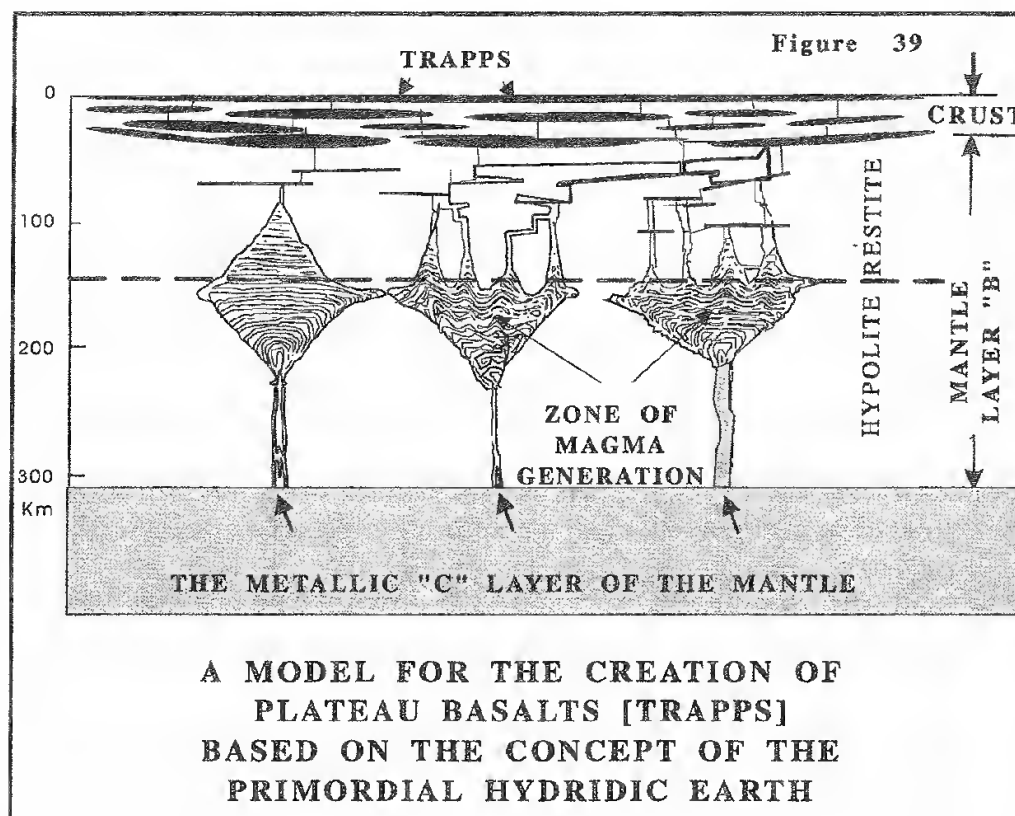
These wedges (Figure 39) could have served as a kind of a "hydrogen conductor," enabling hydrogen and its compounds to penetrate the silicate-oxide shell. It should be borne in mind that the diffusion rate of hydrogen in metals is several orders of magnitude above that in silicates. Inasmuch as we cannot relate trapp formation to intensive flows of heat-carrying hydrogen, and neither can we rely on the heat generated by the water-producing "burning" of hydrogen (because the magma must have been "dry" and reduced), thcn we must consider the eontribution of hydrogen-containing compounds to magma generation. Silanes (Si_nH_m) are thc first in this list, because Si is one of the dominant elements of the C-layer of the mantle.

This prospect, which follows from our geochemical model of the Earth, opens a whole spectrum of notions as to possible energy sources for magma generation. Simple ealculations show that if silane is injeeted into the silicate-oxidic shell, the energy of attraction in the Si-O bond represents an exothermic heat capacity sufficient to melt a mass of rock exceeding by perhaps forty times the total mass of the invading silanes.

Chemical reactions concomitant upon silane pervasion and the creation of Si-O mineral forms will vary, but the ultimate result will progressively be more complicated polymer patterns, from isolated tetrahedra of olivine through the continuous tetrahedral chains of pyroxenes to the continuous ribbons of hornblende and the layered tetrahedra of mica, and lastly to 3-D frameworks of feldspar and quartz: (SiO_4) - (Si_2O_6) - (Si_4O_{11}) - (Si_4O_{10}) - $(AlSi_3O_8, Al_2Si_2O_6)$- -(SiO_2).

Invasive silane, therefore, brings on magmatism. The magmas that result differ from the original melted country rock by diminished proportions of the initial members of the aforementioned sequence and an increase in the succeeding members. Greater complexity of Si-O tetrahedra patterns occurs as quasi-crystalline polymer structures develop in the melt. F.K. Shipulin (1969, 1971) concluded that "...the energy of chemical bonds existing in a magmatic melt is a principal source of the energy that feeds magmatic processes" insofar as "...the latter is unrelated to phase transformations of the melt, but precedes mass crystallization, it ensures high invasive ability of the magma by keeping it a liquid and not-superheated substance." It is noteworthy that superheating causes endothermic depolymerization.

As mentioned, a few grams of silane may cause melting of perhaps 100 g of magma. Hydrogen released in magma generation probably acts as a depolymerizing agent, breaking oxygen bonds, pervading already-formed clusters and giving birth to structural groups like Si-OH. These phenomena are accompanied by decreasing magma viscosity and enhanced injective ability. Melt crystallization results in releasing most of the hydrogen; and the amount of water produced being hardly possible at levels exceeding one or two percent.[8]

Thus, in accordance with the aforementioned model, the proposition that "dry" magma generation requires the total prior oxidation of hydrogen, remains as a possibility. It should be pointed out that significant formation of water cannot occur within a magmatic melt so long as silane invasion is in process, because the concomitant chemical reactions will act as a buffer to maintain low oxygen fugacity along with low partial pressure of water. Low oxygen activity in magma also explains the presence of reduced forms of iron and free hydrogen in trapps.

Let us now review the scenario of causes and effects that relate trapp formation with our concept. Increase in the rate of Earth expansion occurred in the late Paleozoic. Decrease of the curvature of old cratons created fractured zones ("extension strains" from tectonic weakness) at the base of the silicate-oxide geosphere. Intermetallic silicides of the C-layer of the mantle, which were plasticized by dissolved hydrogen, were

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[8] *In the case where silane stoichiomety comprises SiH_4, maximal water content cannot exceed 2.5 wt %. If it comprises the compound Si_2H_2, then maximum water content cannot exceed ca 0.5-0.6 wt %.*

forcibly injected into the fractures as wedges. These were analogous to silane jets entering the silicate-oxidic geosphere. Vast magmatized zones formed within the mantle, which gradually were hydraulically propagated upward in sub-vertical fractures and laterally in horizontally-oriented pressure-release "channels." Eventually, reducing melts of low viscosity intruded the crust and effused upon the Earth's surface. This scheme, as shown in Figure 39, presupposes that magma generation will predominantly be sited in areas of primary undifferentiated mantle (hypolith). This location explains the enhancement of lithophilic elements and high strontium isotope ratios of trapps compared to oceanic tholeiites (Chapter IX).

Thus, the primordially hydridic Earth concept explains some enigmatic phenomena. Primarily, these are the spatial and chronological siting of trapp formations, their mineralogical, petrological, and geochemical peculiarities, and their characteristic morphologies and tectonic settings. Moreover, the author's model of trapp magmatism permits the interpretation of variations in geochemical and petrological properties of plateau basalts as consequences of the siting of magma-producing zones relative to hypolith and restite areas in the mantle (Figure 39). Variations may occur in the vertical positions of intrusions as well as initial depths to magma-generating zones, the depths of the latter migrating upward progressively. Decrease in $^{87}Sr/^{86}Sr$ ratios from earlier to later effluences will correlate with diminishing lithophilic content and may be considered to indicate the removal of a magma-generating zone from hypolith into restite (Figure 40).
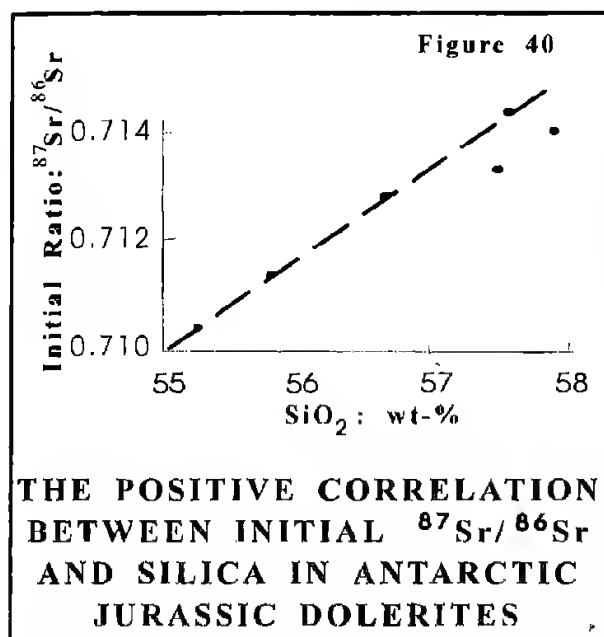
During the author's work on trapp origins for a previous (Russian) version of this book (Larin 1980), a discovery of native Al (as small tabular grains of <1 mm size) in trapps of the Siberian platform was announced (Oleinikov et al. 1978). Further study revealed Mg along with inclusions of ultra-fine mixtures of metallic Mg, Si, and Cu. The discoverors also noted the presence of native Cu, Zn, Sn, and Fe along with alloys of Cu and Zn, Pb, Sn, and Sb.

In the course of investigating these discoveries, and despite severe criticism, the aforementioned authors managed to prove that the native elements they had discovered are unrelated to tectonic processes, and most probably indicate an intensely reducing environment at an early stage of magma generation. This conclusion fits our ideas on the likelihood of oxygen deficiency when intermetallic silicide wedges are forcibly intruded into the lower limb of the silicate-oxide shell.

A more general interpretation can be applied to these data, however. Calculations tell us that magmatic melts superheated to temperatures beyond their crystallization temperature by 250-300°C, are able to assimilate no more than 12-15% of xenogenic materials. This limitation arises from the belief that the latent heat of fusion of the xenogenic materials must

be exceeded before they will melt (Marin 1976). But in my studies of post-orogenic granites, I have observed that intrusives have much greater ability to digest host bodies of biotite granite and granodiorite, as much as 50 vol-%, in fact. Sill-form intrusive bodies in these situations are precluded from receiving any heat by convective transfer from a magma chamber.

The examples given allow us to expound the idea that a magma-generating mechanism is inherent in the trapps and other associated magmatic formations, especially those that are spatially and chronologically isolated from crustal heating and metamorphism.

Figure 40

Initial Ratio: $^{87}Sr/^{86}Sr$

THE POSITIVE CORRELATION BETWEEN INITIAL $^{87}Sr/^{86}Sr$ AND SILICA IN ANTARCTIC JURASSIC DOLERITES

However, no mechanism that permits such irreversible changes as increasing complexity of polymeric structure during generation of magmatic melts, has ever been considered in experiments on petrogenesis. Our view is that experiments involving primary melt produced from pulverized magmatic rocks are analogous to attempts to restore "primary" dough by grinding stale bread crusts and adding water. The latter ignore the irreversibility of biochemical reactions that occur with fermentation and baking (may the author's liberties be pardoned!).

The new Earth model compels our attention to the irreversible reactions that result in increasingly complex Si-O polymeric structures, during the evolution of magmas. Perhaps most elegant and varied are liquid segregations, differentiations exhibiting, in some cases, immiscibility within the magmas. These phenomena deserve thorough research.

CHAPTER VIII

STRUCTURAL FEATURES OF OCEAN FLOOR IN THE LIGHT OF EXPANDING EARTH

The abundant data on ocean floor structure, obtained over the last 15-20 years, enable geologists to progress from merely regional to worldwide interpretations of geological phenomena. The aim of this book is not a comprehensive presentation of facts, because these are well known. At present, we disagree with the widely accepted view of certain structural features of the oceans as evidence for plate tectonics. But, because this view is such a deeply rooted conviction by numerous investigators, we must necessarily dwell upon its basic premises to show that it is founded on an insufficiency of facts. Under the circumstances, this is tantamount to a demonstration of unreliability for the concept itself.

8.1 Spreading vs plate tectonics

The spreading seafloor idea was inferred from the observed banded character of magnetic field anomalies that are found to run parallel to the global system of mid-oceanic ridge axes. The magnetic anomalies are arranged symmetrically with respect to median rift valleys, and the ages of their rocks are systematically greater with incresed distance from ridge axes, toward the continents. This means that gaping ocean bottom replaced initially narrow rift crevices which had previously divided the integral pre-continent, "Pangea." It would seem that these data naturally suggest Earth's expansion, as the oceans encircle the globe and the continents lack compression zones to equalize the effects of the ocean expansion structures. This absence of equalizing features ean be stated quite definitely for Neogene - Quaternary time.

However, only a few scientists (e.g., Heezen 1966) have adhered to this constraint, and many avoid the interpretation of planetary expansion in their interprctation of spreading. The reason for their avoidance is, evidently, confidence in the mechanistic concept of convective plumes in the mantle as the explanation for tectogenesis. From this hypothesis came the idea that spreading of the mid-oceanic ridges may be attributed to ascending mantle, to "zones of divergence of convection cells."[1]

According to this viewpoint, continents are pulled apart from the point of emergence of the convecting mantle. They are dragged to the sites of

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[1] *For instance, S.K. Runcorn [1975] said that "... thermal convection is, a priori, a process explaining continental drift and plate motion." He also believes that "... the phenomenon of drift is a decisive proof of the existence of convective flows..." (Runcorn 1972). Obviously, it is difficult to justify that sort of argument.*

descending convective flow, where they stabilize in the balanced field of opposite drag forces (Dietz 1974). Naturally, this mechanism, which envisions a sort of escalator, requires no planetary expansion.

The dating of banded magnetic anomalies made possible the determination of the rate of expansion of mid-oceanic ridges over the last several score million years. This rate turns out to be different at different spreading axes, and an uneven latitudinal addition to the Earth's surface is evident. However, the Earth did not lose its sphericity, which, according to X. Le Pichon, evidences the constancy of its volume on the one hand, and implies on the other, some adequate compensatory processes of the Earth's crust to absorb the added mass and to provide constancy of total surface area (Le Pichon 1974).

Investigators, quite reasonably, paid initial attention to systems of deep-sea trenches and island arcs that exhibit extremely high levels of volcanic activity, particularly those occurring in vertically-extensive, sharply-defined zones of intense seismic activity and extreme deviation from isostatic equilibrium, which is indicative of tectonism ("Benioff-Zavaritsky" zones). This led them to interpret the island arc/deepsea trench systems as places of lithospheric absorption ("subduction;" Isacks et al. 1974).

However, mid-ocean ridges encircle the globe, extending continuously for about 80 thousand kilometres, while the total length of the Benioff-Zavaritsky zones is much smaller, and of discontinuous nature. The coasts of the Atlantic and Arctic Oceans are devoid of subduction zones, and those of the Indian Ocean are limited to its northeastern shores. Thus, in order to explain movement of newly-formed crust from the axes of mid-ocean ridges to subduction sites (i.e., to the Zavaritsky-Benioff zones) on a global scale, the adherents of the concept divided the lithosphere of the planet into large plates. These schemes are widely known. However, it is still difficult to concur with the idea of including within the limits of single lithospheric plates, whole continents and vast ocean-floor areas, which differ internally in evolution and deep structure.

Manifestly, the hypothesis of the primordially hydridic Earth, which implies planetary expansion, is an alternative to the plate tectonics concept. To test a scientific hypothesis means to test theoretical expectations against observation. Let us try to resolve the choice of alternatives using the observations on transcurrent faults. These are indispensable structural components of mid-oceanic ridges. J.T. Wilson (1965) used the concept of spreading to predict reverse displacements on these faults, the opposite of the motion needed to generate the ridge by strike-slip fault motion (Wilson 1974). Study of earthquake mechanisms from first arrival times of seismic waves actually did reveal a reverse, or "transform" (according to Wilson) relative displacement on the fault plane in the segment between the offsets of the mid-ocean ridge crest (Sykes 1967). It has now become generally accepted that these transform faults are convincing evidence for plate tectonics.

It should be pointed out, however, that the reverse character of

displacement within a transform fault between disconnected ridge segments manifests merely the legitimacy of the concept of spreading. It does not evince any deep-sourced mechanism. Nor is any preference implied either for the theory of expanding Earth or for the plate-tectonic concept with mantle convection. Nevertheless, the solution of the dilemma is, in our opinion, implicit within certain particular transform fault features that have been overlooked up to now.

If the plate-tectonic concept is valid, transform faults should be pure strike-slip faults with tightly lapped fault planes, and such tight lapping should be reinforced with distance from the ridge axes. This condition follows, because the extended axial zone of newly-forming crust comprising the axial parts of ridges and rift zones greatly exceeds the total length of the Zavaritsky-Benioff zones.

The expanding Earth hypothesis suggests a quite different character for transform faults. Specifically, ridge length ought to grow, increasing simultaneously with axial expansion on both sides of the axial rift valley.[2] That is to say, there should be a longitudinal component along with and equal to the transverse one. Otherwise ridge continuity and planetary sphericity could not remain constant as Earth volume increased.

Transform faults offset the axes of spreading along with the rift valleys, which are the zones of crustal rock injection. No strike-slip displacement is possible outside these limits nor any continuation of the transform fault beyond where it reaches the boundary of the a zone of spreading

Longitudinal extension of the ocean floor progresses across numerous transform faults. For example, there are many score of these in the Atlantic Ocean. Consequently, the extension component within the transform area must be just tenths of the strike-slip component, and that is why it is not evident on seismic surveys. However, a transform fault must be a pure extension outside the limits of the spreading area, where the strike-slip component does not develop. The greater the distance from a fault area to the ridge axis, the bigger the disparity must be. This situation can be illustrated by a simple calculation. Let us assume that the average rate of spreading for the Atlantic Ocean is 2 cm/year, and the number of transform faults is 100. Hence, the velocity of the longitudinal extension component of each fault will be 0.02 cm/year; consequently, the gap will be 2 km in 10 Ma and 10 km in 50 Ma. The segment of the fault 10 Ma old will be 100 km away from, the ridge's axis, and that 50 Ma old, 500 km away. Therefore, in the light of the hypothetically expanding Earth, transverse faults and the gap must gradually increase with growing distance from the axial zone. The gaping fault is morphologically expressed on the surface by a graben, and

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[2] *The supposition of ridge length incrementation due to continent separation is also based on the fact that ridge lengths exceed lengths of primary continental ruptures, a fact which can be determined from the lengths of the modern continental slopes (Chudinov 1978).*

consequently, the transform faults on the expanding Earth must be grabens, their width gradually growing with distance from ridge axes (Figure 41a).

Moreover, a ridge axis need not be offset by transverse faults that are brought about by Earth expansion (Figure 41b). Finally, a transverse fault that is a gaping fault that owes its origin to longitudinal extension of the ridge, may be unilateral, that is to say it may lack a continuation on the other side of the rift valley (Figure 41c). Behavior of this sort is inconsistent with the plate tectonics concept.
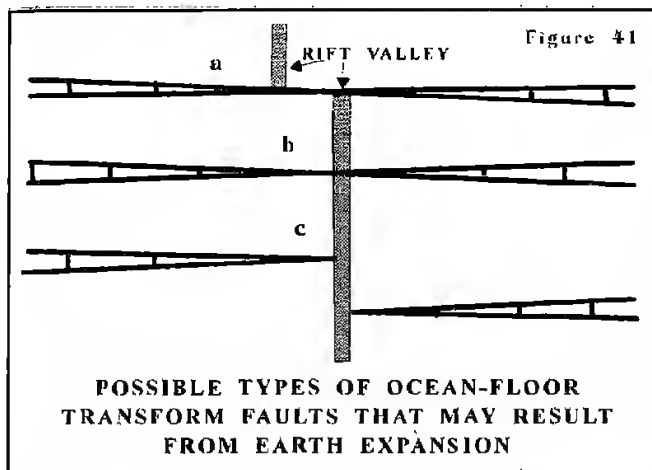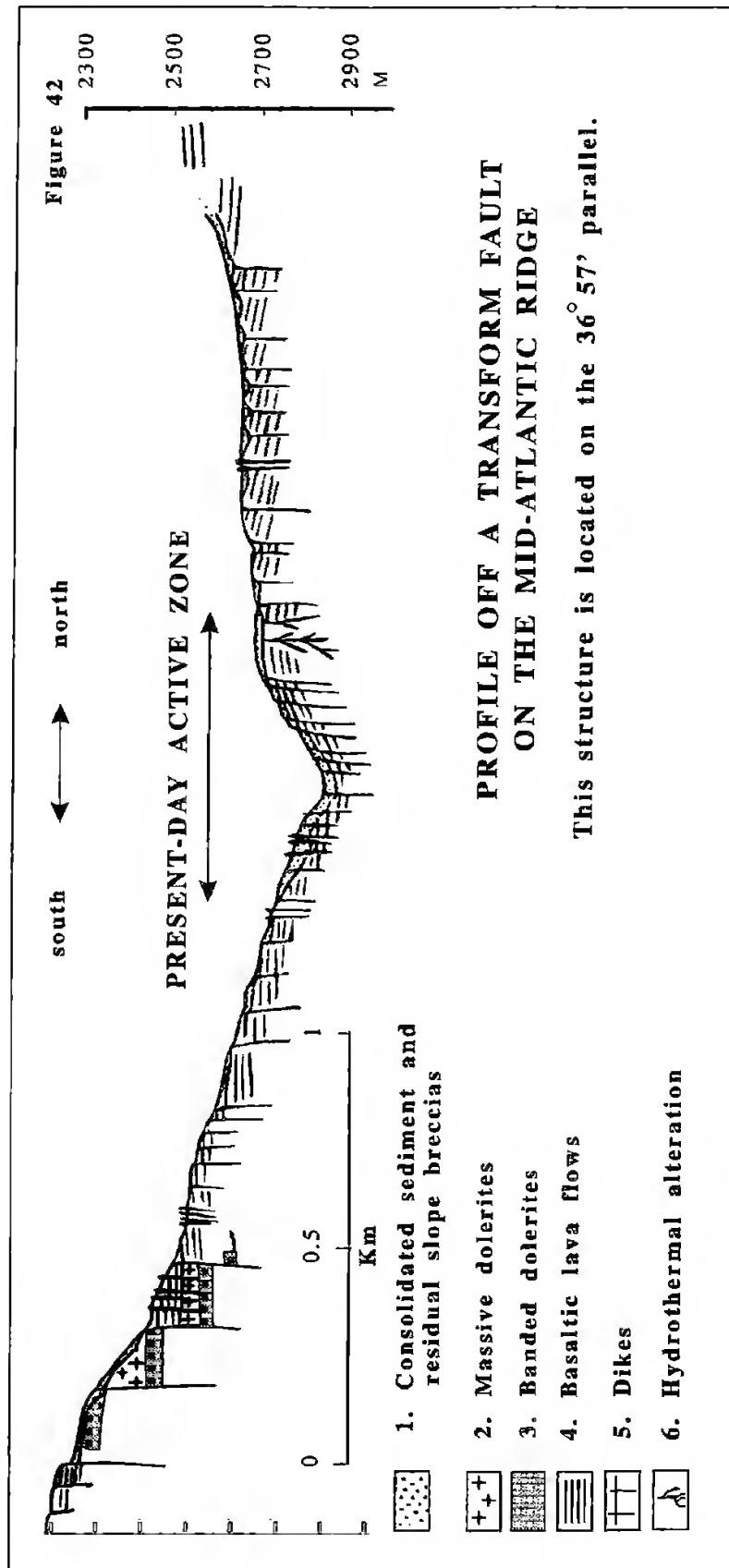
Therefore, the anticipated motion on faults, which are oriented transverse to mid-ocean ridges, is, from a plate tectonic perspective, opposite to that inferred from an expanding Earth perspective. Consequently, the nature of transform faults, as understood in terms of one or the other concept, is sufficient as a criterion for verification of the expanding Earth vs plate tectonic alternatives.

This test may be deferred for future use, when there are sufficient detailed research data on transform faults. Presently, however, available data, albeit fragmentary, still allows a choice between the foregoing contradictory points of view. First of all, the bathymetric charts of oceans show transform faults to be accompanied by negative relief. This observation evinces a tectonic regime of extension in the process of fault instigation and propagation. The recently improved bathyscaph technique permits deep-sea mapping and makes possible examination of minor tectonic features including individual elements on the North Atlantic mid-ocean ridge.

One particular transform fault near the 36°57'N parallel (ARCYANA 1975) turned out to be a typical graben characterized by flanks shaped by multistage landsliding (Figure 42). These are obviously extensional structures. In another locality, a many-faceted study of the zone of transform deformation near Ascension Island in the South Atlantic finds the fault valley consistently widening with distance from the ridge axis increases (Van Andel et al 1973; Figure 43).

Figure 42

PROFILE OFF A TRANSFORM FAULT
ON THE MID-ATLANTIC RIDGE

This structure is located on the 36° 57' parallel.

PRESENT-DAY ACTIVE ZONE

south   north

Km

1. Consolidated sediment and
   residual slope breccias

2. Massive dolerites

3. Banded dolerites

4. Basaltic lava flows

5. Dikes

6. Hydrothermal alteration

43A
GEOLOGY

Figure 43A

1. Ridge slope
2. Ridge axis
3. Rift valley
4. Fault zone

ASCENSION
ISLAND
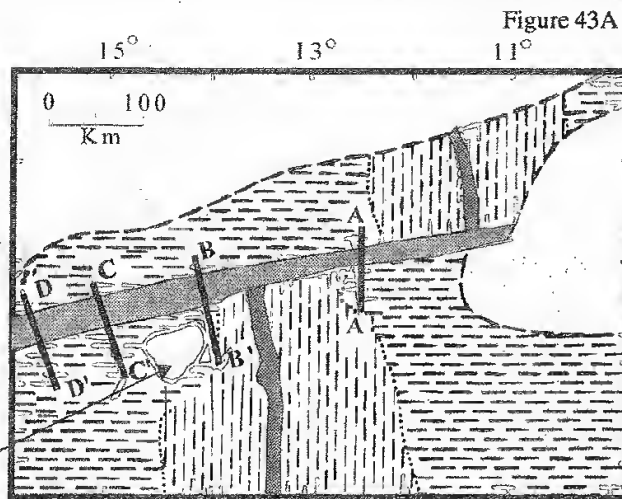
**LOCATION OF THE POLYGON SHOWING
THE RIFT VALLEY AND OFFSET RIDGE AXIS**

Figure 43B

43B
Bathymetry

Contours at 500-m intervals are
shown in 100's of metres

ASCEN-
SION
IS.

Figure 44

SEISMIC SURVEY RESULTS IN THE
VICINITY OF THE
ASCENSION ISLAND FAULT ZONE

The locations of seismic lines appear on Figure 43A

**MAGNETIC ANOMALIES
IN THE VICINITY OF THE
ASCENSION FRACTURE ZONE**

Figure 45

SOUTH LATITUDE

7°

8°
16°

14°

12°
+ 7°

FAULT ZONE

ASCENSION
ISLAND

50 Km

1 Negative
anomaly
2 Positive
anomaly
3 Extrapolated
anomaly
4 Rift valley

Seismo-acoustical soundings carried out within the limits of the valley ascertained the graben structure, the width of which also increases wi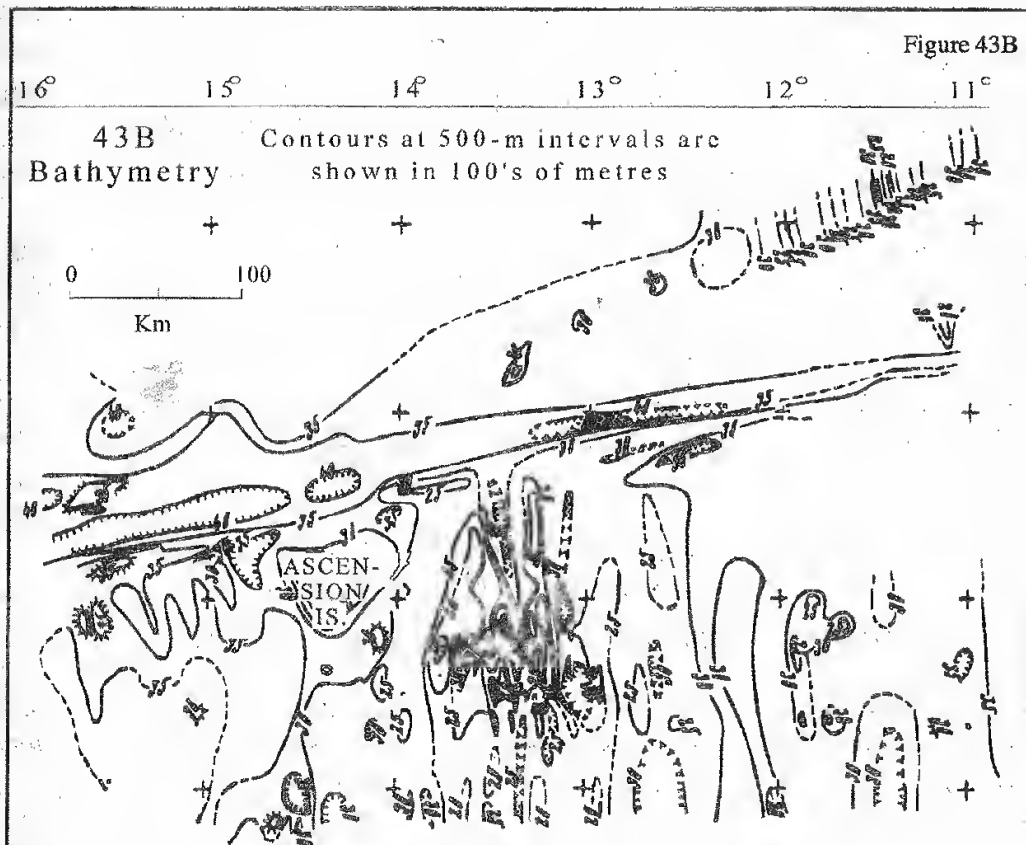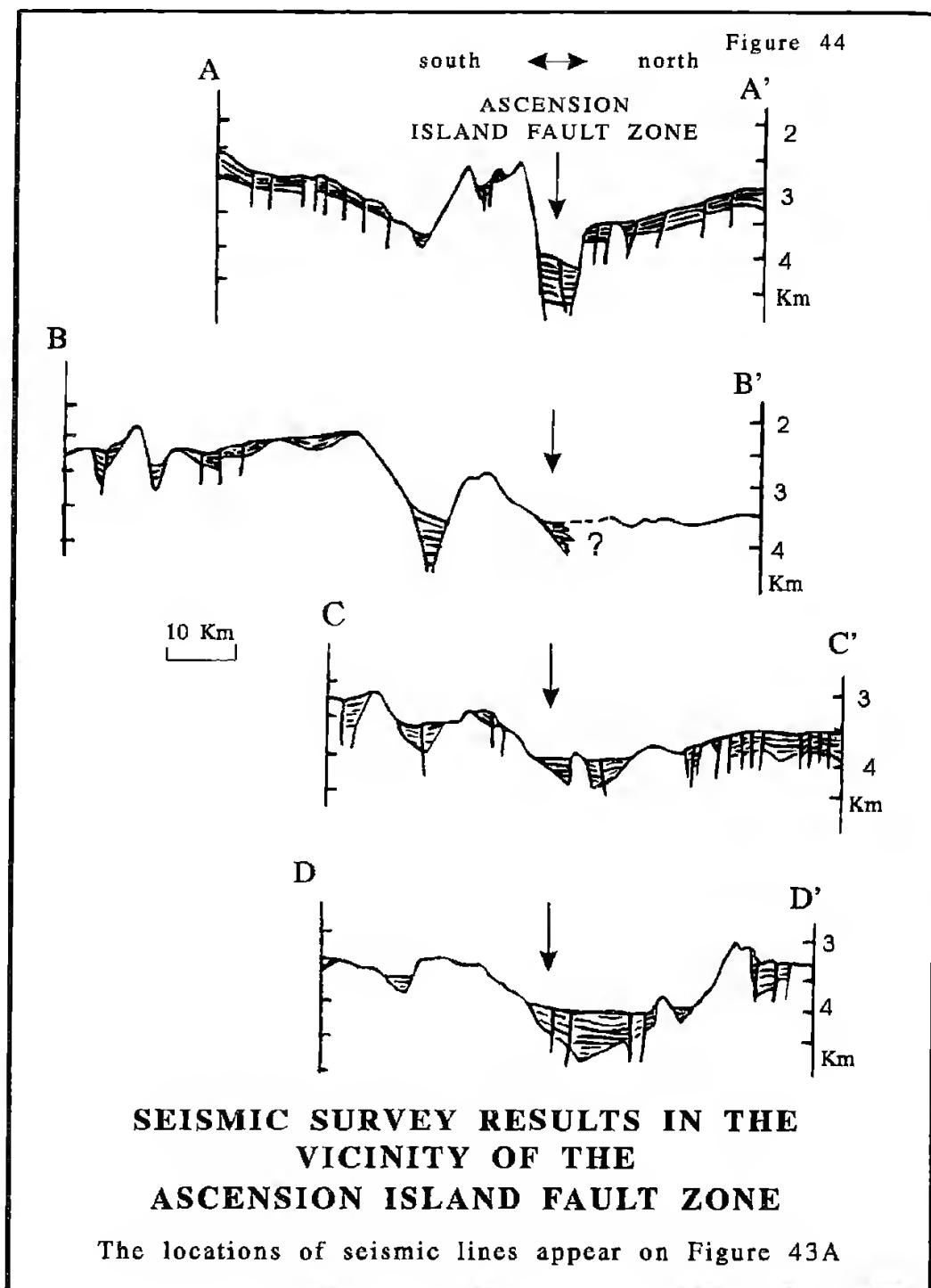th distance from the middle of the ridge (Figure 44). Finally, magnetometrics reveal banded anomalies sub-parallel to the deformation and gradually diverging (Figure 45) concordantly with the widening of the graben valley. All these data may be interpreted as evidence for a gaping style to the transverse faults outside the limits of the transform area and of the gradual widening of the gape.

As reported by G.B. Udintsev, transverse faults without displacement, as well as unilateral gaping faults (Figure 41b,c) have been recently discovered in many places and are evidently unexceptional. It will be shown farther on that our model anticipates compressive extrusion of blocks in both the rift valleys and the transverse fault valleys. These should complicate the structure of expanding grabens with interior horsts.

Thus, it is very desirable that study of the minor features associated with the transverse faults should be stimulated so as to improve our apprehension of the longitudinal component of ocean floor spreading. Such an investigation appears to be of crucial importance for determining the validity of one or the other concept.

8.2 A model of ocean evolution

The suggested model envisages a substantial (probably multiple) incrementation of Earth's volume, which must, in addition, have accelerated through time. Oceans are interpreted as giant extension structures. Their origin and development at late stages in Earth evolution reflect processes of augmentation of the existing system and its unification into a global network of extension structures. These extension features developed coincidentally with a shifting of the decompaction front, inward toward the planetary interior.

Proceeding on the premise of the suggested model, let us consider the probable dynamics of ocean evolution that would result in the modern deep

basins. Let us also consider how the model correlates with available geophysical data.

The first problem that arises is to locate the source of the material that fills the gape. In our view, fill is a partial displacement, laterally, of old mantle material that has been extruded from beneath expanding continents. Most likely, this is vertically displaced material that emerged at the decompaction front after hydrogen degassing. Zones of tectonic weakness through which these materials ascend are thought to pierce the entire mantle.

According to our model, the first pulse of tectonism presaging chimneys of weakness should have occurred at the base of the mantle at the interface with the decompaction front. From there it should have spread upward and simultaneously filled with substances elevated from the deepest layer of the mantle. This layer may contain residual hydrogen in the diffuse form of a proton gas, its concentration already insufficient to compact metals but perhaps still sufficient to cause a sharp drop in viscosity, and thusly to provide effective plastic flow. The existence of a plastic layer at the base of the mantle is shown by geophysical data in the form of a significant decrease in seismic wave velocity in the 100-200 km zone directly adjoining the core (Bolt 1973).

Taken in the light of our concept, the deep-seated processes that brought about formation and evolution of oceans can be traced to origins in the extension zones at the base of the mantle and above the planetary decompaction front, through which plastic matter in the form of diapirs ascends to the upper geospheres from the shell that envelops the Earth's core. This plastic substance consists of metals made liquid or plastic by protonized hydrogen.

These diapiric masses had been in the Earth's core up to the moment of becoming active in geodynamics. Therefore, evidently, original oxygen could not have been lost, because the diapirs, unlike the mantle, had not been exposed to hydrogen purging. Notwithstanding, diapirism should have been accompanied by *some* hydrogen emission; and its outflow should have redistributed the remaining oxygen. This would have had the likely result that intermetallic silicides in the head of the diapir would have been transformed to silicates by oxygen evacuated from deeper zones by the ambient hydrogen.

Consequently, besides extension and thinning of old silicate mantle, the opening of the ocean was accompanied by the formation of a new silicate "buffer zone" (a young supra-mantle layer). According to our model, this would have spanned the ocean basins below the old silicate-oxide shell. An idealized scheme for the inception and evolution of ocean basins from initial riftogenesis to the modern mature state is shown in Figure 46.

A MODEL FOR OCEAN FORMATION
BASED ON THE NEW THEORY

a) "Infancy"
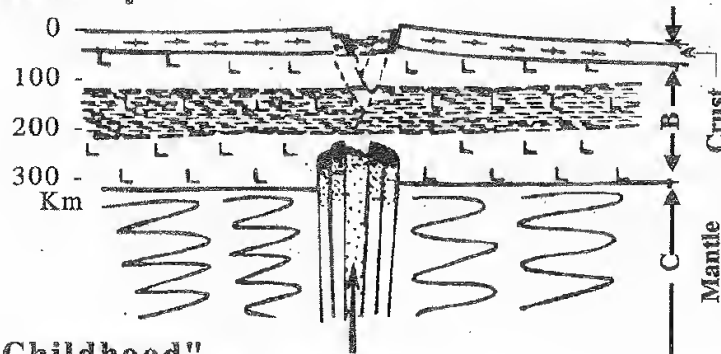
b) "Childhood"

c) "Youth"

d) "Maturity"

Figure 46
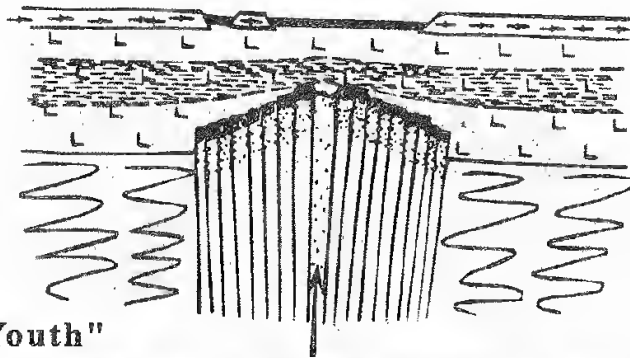
According to this scheme, the ocean was a simple and, most likely, a shallow, marine basin in the first (juvenile) stage of basin evolution. This

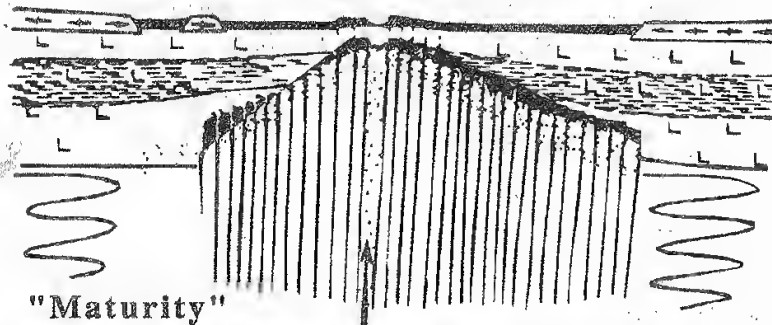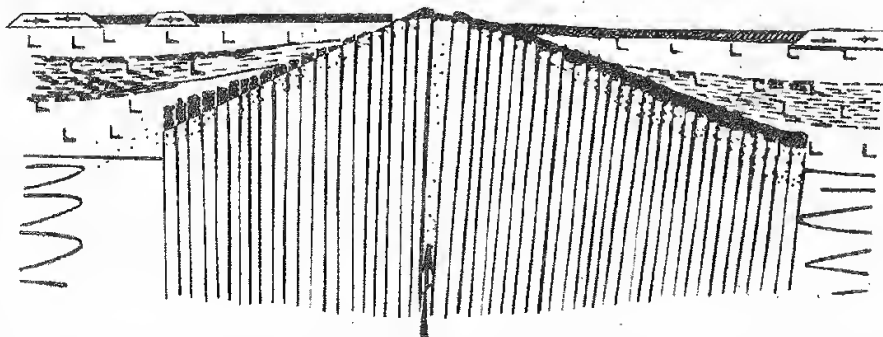period lasted until continuity of the asthenosphere was disrupted. As soon as that happened, oceanic structure changed, and there appeared along its axis a median uplift, as if reflecting the pattern of the newly-forming ultra-deep diapirs flanked by the young silicate buffer, and rising nearer and nearer to the surface of the planet. While in the "youth" stage (Figure 46c) the mid-oceanic ridge was produced by the forcing out of old mantle blocks through the overlying cover. A piston-like action by deep sub-oceanic diapirs is envisioned. At later stages the newly-formed silicate buffer comes to the surface, and the "mature" stage of ocean evolution begins (Figure 46d).No further structural change is envisioned, but dimensional increases, owing to spreading transverse to the ridge, and growth of the extension component in transform faults are possible. The interpreted deep structure of the ocean that corresponds to the mature stage of its evolution, is shown in Figure 47.

Figure 47

THE "MATURE" STAGE OF DEEP OCEAN STRUCTURE

1. The planetary shell of silicate/oxide composition
2. Older metallic subcontinental stratum
3. Younger metallic oceanic substratum, showing oxidized upper levels (densely stipled)
4. Present-day zone of decompression from which metallic matter is injected into bowels of rift zones
5. Outer planetary core
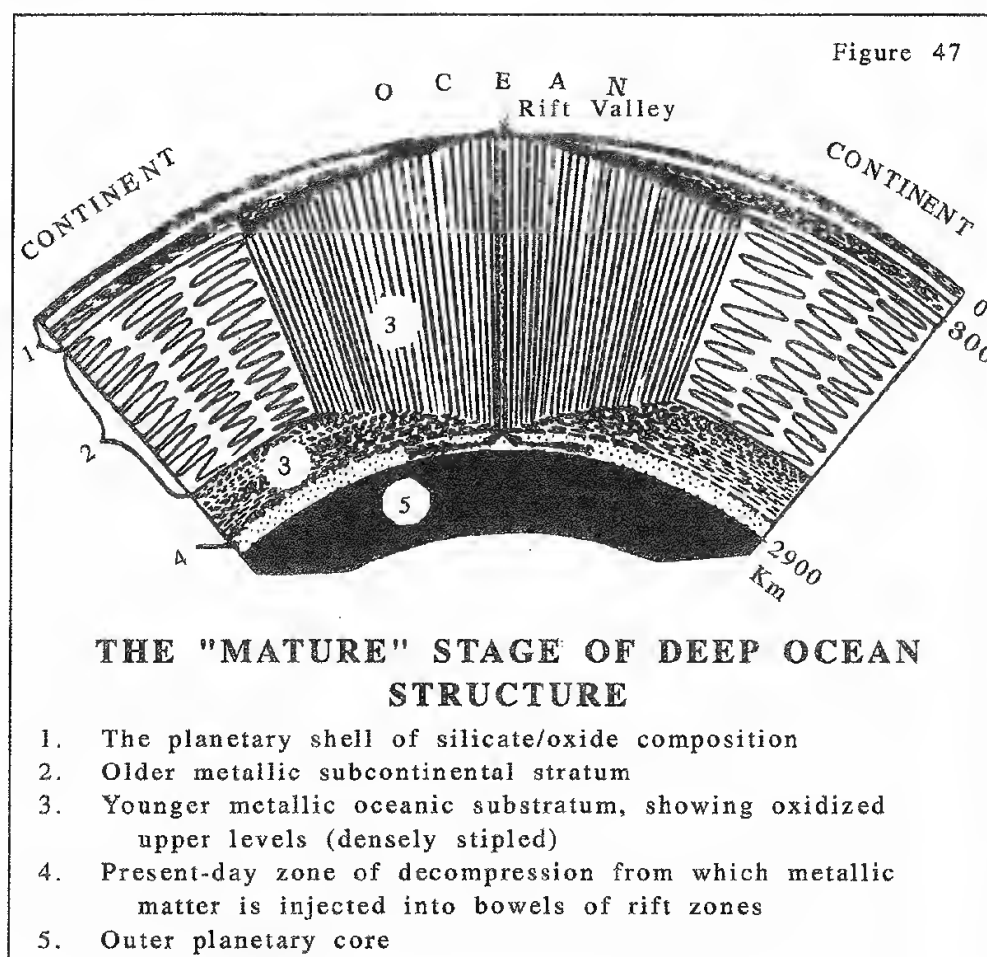
Intermetallic silicides themselves cannot reach the surface, because their inevitable encounter with the hydrosphere as they approach the surface will be accompanied by a vigorous chemical interaction with the oxygen from the water. A silicate "rind" forms first and may melt. Oxidation of silicides (which include silicon, magnesium, calcium, aluminium, and other

metals) is an extremely exothermic process.

The intrinsically cold state of diapirs of intermetallic silicides that intrude the axial parts of riftogenic zones, will be described in coming pages. It is not impossible that their temperature upon intrusion is even below 0°C, and that only later are they warmed by the heat exchange of silication and heat conducted from earlier diapirs. It follows from the above that melting of the previously mentioned "rind," cannot be supported by heat carried from depth. Melting must proceed, moreover, against the background of effective cooling influence of depth, an effect that is reinforced by the high thermal conductivity of intermetallic silicides.

Under such conditions, melting within the limits of the "rind" can only be sustained so long as heat-replenishing reactions continue. We may even suppose that each dike with its associated cover in the axial regions is a consequence of an individual event of melting. For instance, we can imagine the following chain of events: (1) expansion causing the appearance of fracture zones through which water of the hydrosphere reaches the intermetallic silicides, (2) oxidation to silicate-oxide compositions and melting in the water-contact zone, (3) intrusion of melts into fracture zones, filling them with dike magma, (4) staunching of the flow of water into the zone of reaction and with it the cessation of heating, and (5) efficient heat escape by conduction in all directions, with rapid cooling and crystallization. If expansion continues, newly-formed dikes are again ruptured by the intrusive diapiric activity, and the whole cycle repeats again and again as long as the ocean expands. This activity means continuation as long as planetary expansion persists and "wedges" of intermetallic silicides intrude the axial belts of the oceans. Thus, it seems that each episode of "wedge" formation on an axial belt of the ocean correlates with multiple events of dike intrusion. This process, when all is said and done, explains the formation of "complexes" of parallel dikes.

The indicated mechanism of formation for these remarkable complexes is enlightening on two points, namely, why dikes are short vertically but long horizontally, and why the melts, which are generated with evident involvement of the hydrosphere are characterized by exceptional "dryness." It is noteworthy that, within the framework of our interpretation, there is no necessity to consider a magma chamber as feeding the dikes either internally or peripherally to a magmatic center concealed in the interior. We emphatically disagree that there is any such "deep-seated" center (joining all dikes) at the stage of formation of the complex of parallel dikes.

Along with vigorous formation of the "silicate-oxide rind," there should be concomitant silication of the upper part of the intermetallic diapir by hydrogen purging, a process likely to be pervasive and ongoing. We think it is precisely this process that is of major importance for addition of the silicate "buffer" under the oceans.

The density of silicides is approximately 3.1 g/cm^3. The density of silicates (olivines, pyroxenes) that form underneath oceans is of the same order. But silicates contain up to 45% by weight of oxygen, which implies an approximate

volume doubling in the process of silication. This doubling should show up in oceanic geomorphology.

It has been shown above (Chapter VI, 4) that the flow of hydrogen is liable to break up into individual local, more powerful flows, i.e., to coalesce into jets, even if its density is originally uniform. Consequently, hydrogen will arrive in individual jets, and correspondingly, the protrusions of newly-formed silicate blocks will bulge as isolated pillars or crests, depending on the form of the jets. However, because the rate of hydrogen diffusion in metals is much higher than in silicates, hydrogen flows sometimes have to make new paths through areas previously unaffected by silication, whence new intrusive blocks will appear in these areas.

The foregoing details are dwelt upon in order to show that our model of the formation of oceans does not give the geometric stringency and ordered relief pattern on mid-oceanic ridges that is represented by some physiographic maps of the ocean floor. Rather, according to our concept, the relief should be chaotic, with alternating positive and negative forms both across the ridge and along its strike. Recent detailed bathymetry of individual ridge segments reveals this chaotic pattern of relief, with en echelon positive and negative forms alternating along strike (Peive 1975; Udintsev 1989).

According to our model, the age of rocks of the silicate buffer that forms the median ridge ought to correspond to the tectonic age of the ridge itself. However, the data on absolute ages vary over a wide range, with values from hundreds to thousands of Ma.

These disparate values may be explained by two circumstances. First, it is not impossible that within the limits of the ridge there exist relics of the ultramafic-serpentinite mantle that had once lain beneath the continental margins but was extruded to the ocean floor as the outer geospheres were expanded.[3] Blocks of mantle may be raised by the same extrusive phenomenon that created the ridge. This situation is possible at all stages of evolution of the ocean, including its mature stage (Figure 46). Second, we should not forget the phenomenon known as "leapfrogging" that appears to be widespread. "Leapfrogging" envisages alternate functioning of two zones of extension. The model of oceanic evolution, shown in Figure 46, is geometrically idealized, whereas it is quite possible that the original riftogenic structure was branching. Made up of two brachial rifts in some sections instead of one, rifts would be inherently more complex. Our model of the expanding Earth allows various segments to be active simultaneously so as to lead in all cases to the same effects; an old block made up of old mantle retained in a young ocean.

Having generalized from the data on dredging and drilling of the Atlantic Ocean floor, A.V. Peive recognizes that crystalline rocks, excluding young basalts, "... show a clearly defined affeet of compression, not extension, throughout the mid-Atlantic Ridge area" (Peive 1975). There is no difficulty

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[3] *The mantle, differing from the crust in this behavior, is warmed to a greater extent, and is consequently capable of being expanded plastically.*

in explaining this apparent paradox within the framework of our model, which envisages episodic ocean expansion with alternating stages of extension and quiescence, during which diapiric intrusion of silicated metals from below takes place. The silication is accompanied by considerable volume increase, and consequently, is capable of providing compression both for the blocks experiencing silication while bulging upward and for their component rocks. Lateral pressure can induce intense dynamic metamorphic effects. These can, if containment pressure is sufficiently high, create stress-amphibolites and schistose plications of crystalline rocks, (as mentioned by A.V. Peive) At lesser depths the volume increase causes crushing, cataclasis, and mylonitization. According to our model, each block from the silicate buffer involved in the median ridge, must once have undergone extrusion, including direct contact with the next extruded block and the exertion of lateral pressure. This is our explanation of the general influence of intense dynamic metamorphism on the crystalline rocks of the ridge.

This kind of metamorphism can not be localized in time, since it is not connected with a single episode of diastrophism but constantly accompanies the process of formation of a median ridge. It is, therefore, distinct from metamorphism of continental fold belts. We should mention that active diapirism in the bowels of a ridge as a result of compression would necessarily be accompanied by melange. The resulting irregular topography is a definitive form that provides the conditions for the formation of olistostromes.

Phenomena which cannot be explained on the basis of plate tectonics include: (1) regional compressional metamorphism of crystalline rocks of a ridge; (2) the presence of blocks of old serpentinite-ultramafic mantle within ridge limits; (3) the peculiar structural features of evolution affecting ocean floors that had long existed as simple basins without median ridges; (4) the episodic character of ocean floor spreading; and (5) the development of gapes on transform faults, thus demonstrating ridge spreading.

Adherents to the plate tectonic concept do not pay due attention to compressional metamorphism of crystalline rocks within the limits of the ridge or to the episodic character of the ocean floor spreading, both of which are incompatible with mantle convection as a causative mechanism for plate motion. By contrast, the ocean formation model derived from the hypothesis of a primordially hydridic Earth conforms well to the whole complex of known geological-tectonic data. It facilitates the reconciliation of such seemingly incompatible phenomena as the spreading and transform fault gaping in the axial sector of the ocean under conditions of simultaneous ridge growth and compressional metamorphism.

It is interesting to note that at first our hypothesis was sharply criticized, because it implied that the axial zone of mid-oceanic ridges must be the site of jets of escaping hydrogen. These were not known at that time. However, in studies carried out by V.I. Kononov, B.G. Polyak and others, it was ascertained that hydrogen flow in the median zone of Iceland, was confirmed by the isotopic composition of helium in the gas from thermal springs

(Kononov & Polyak 1974, 1975; Arnorsson et al., 1974]. Subsequently in quite numerous publications by various authors on the same subject, the phenomenon has been discovered to occur on a large scale in median ocean sites. The criticism ceased.

As for the causes and mechanism of the geosynclinal process, it was our statement that an oceanic basin could revert into a geosyncline only if extension had not exceeded some certain limit. This limitation follows from the comparison of the schematics of formation of the ocean (Figure 46) with the model of the geosynclinal process (Figure 18). Unambiguously the ocean structure is shown to be capable of regeneration into a fold belt only if the period of opening occurs in the "juvenile" stage of ocean development. Later, at more mature stages, the silicate-oxide shell of the planet has significantly thinned, and asthenospheric continuity is broken. This condition precludes the possibility for initiation of the "throat" zone and the asthenospheric funnel, which are required to bring on tectonic imbrication and subsequent orogenesis.

According to our model, the width of the opening in the oceanic crust for a eugeosyncline may not exceed several hundred kilometres. However, the Asian paleoceans (the "Paleozoides") evidently exceeded 1 000 km across and, nevertheless, ended as geosynclinal fold belts. It is necessary in this case to take into account the specific conditions whereby initiation and evolution of "paleoceanic" basins took place, because, by comparison with modern oceans, they are seen to display "... a primary difference in sequence of formation, and consequently, in particulars of tectonic evolution" (Ruzhentsev 1984). There is, therefore, not necessarily a contradiction between our hypothesis and the statement as to the impossibility of regeneration of a mature ocean into a fold belt.

Having generalized available data on the Asian Paleozoides, S.V. Ruzhentsev has come to the conclusion that there were not only one but several spreading axes (transverse to the section). He finds that spreading in each of them did not exceed some fractions of a millimetre per year, and that there were several island-arc systems (also in the transverse direction) at the transition stage, among which the ensimatic systems alternated with the ensialic ones.

Let us discuss this particularity within the framework of our model by assuming (a) gradual coalescence of extension structures, which were at first scattered into a single rift system, such as we find at the present stage of Earth evolution, and (b) acceleration of the Earth's expansion from past epochs to the modern one. In this connection, we cannot assume that paleoceanic basins were like those of modern oceans with only single spreading axes. In the past, expansion was more than likely distributed among numerous spreading zones and was, in addition, less intense. Thus, between such multiple zones older sialic blocks of various dimensions should normally have been preserved as archipelagoes of microcontinents separated by a network of riftogenic structures of the Red Sea type. Expansion, lesser in scale than at present and spread over a vast area, could hardly have led to

substantial thinning of the silicate-oxide shell or to disruption of asthenospheric continuity.

Later, at the stage of hydrogen degassing from the core, following Earth expansion, the entire region could have become the site of initiation of tectonogenes with the whole spectrum of accompanying phenomena, including folding and orogenesis. Here we should remember the more dispersed character of the deep hydrogen ambience in the past, a subject that was discussed previously. Commensurately, not one but several tectonogenes would have originated within the confines of riftogenesis. Tectono-magmatic activity connected with these tectonogenes could superimpose itself both on regions of oceanic crust and on older sialic blocks, thus providing rationale for specific derivative ensimatic and ensialic intrusions.

The network of anastomosing tectonogenes is attributable to interactivity among streams of hydrogen, with branching, merging, and coalescence in the Earth's interior, and creation of intricate patterns of viscoplastic flow in the asthenosphere. These activities set the stage for surface structures of extreme complexity that are hard to decipher.

Thus, our model can explain the special character of "paleoceans." It imputes irreversibility to the evolution of ocean structure. It resolves the enigma of why, despite spreading of their median zones, no modern ocean has developed into a fold belt. Our model suggests that the peripheries of the oceans are "scarred" with fold belts (Figure 21), because these regions are underlain by asthenosphere, and consequently are subject to tectonic imbrication.

8.3 Geophysical peculiarities of oceans

The axial parts of mid-oceanic ridges are characterized by anomalous heat flow and axial magnetism, which is commonly an order of magnitude above that of adjacent magnetic signatures. In addition, a lens of so-called "crust-mantle mixture" is observed by seismology under axial ridges. The seismic wave velocities of these lenses vary from 7.0-7.8 to typical mantle values of 8.2 km/sec and more. Because there is no regular pattern of arrangement of the reflectors, it is not possible to distinguish the individual low and high-velocity blocks.

Gravimetric studies reveal deep negative gravity anomalies over ridges (Bouguer lows), their minima falling on the axial zones of the median ridges. These anomalies, which attest to low densities of the crust-mantle mixtures, have been evaluated by various authors as falling within the limits of 3.05-3.15 g/cm^3. Seismic studies show that the depth of occurrence of the crust-mantle mixture beneath the bottom of well-defined rift valleys in some places does not exceed several kilometers (Figure 48).

At present, all the above-mentioned geophysical phenomena are commonly attributed to large, still-cooling intrusions of ultramafic rocks emplaced in the axial zones of ridges. High pluton temperatures are thought to provide the heat flow and to signify active decompaction. This condition lowers seismic wave velocities and induces negative gravity anomalies. However,

the observed decompaction would require a temperature of approximately 1000°C. That raises the question of just what causes magnetic anomalies. Magnetic susceptibility falls to zero under temperatures such as these, which substantially exceed the Curie point.[4] That renders the concept of "hot intrusions" a dubious one. Moreover, the strength of the axial magnetic anomaly sharply decreases (by as much as an order of magnitude), when the axis divides in the process of ocean-floor spreading.

Figure 48

1 Superficial deposits

2 Basement, the second layer

3 Oceanic crust, the third layer

4. Less-dense mantle with velocities of 7.0-7.3 km/sec. Slant hachures indicate regions of velocities of 8.2 km/s or greater There is an absence of data to establish the continuation to depth of the high-velocity zone.

5. Mantle with velocities of 8.2-8.4 km/s

After Talwani et al 1965
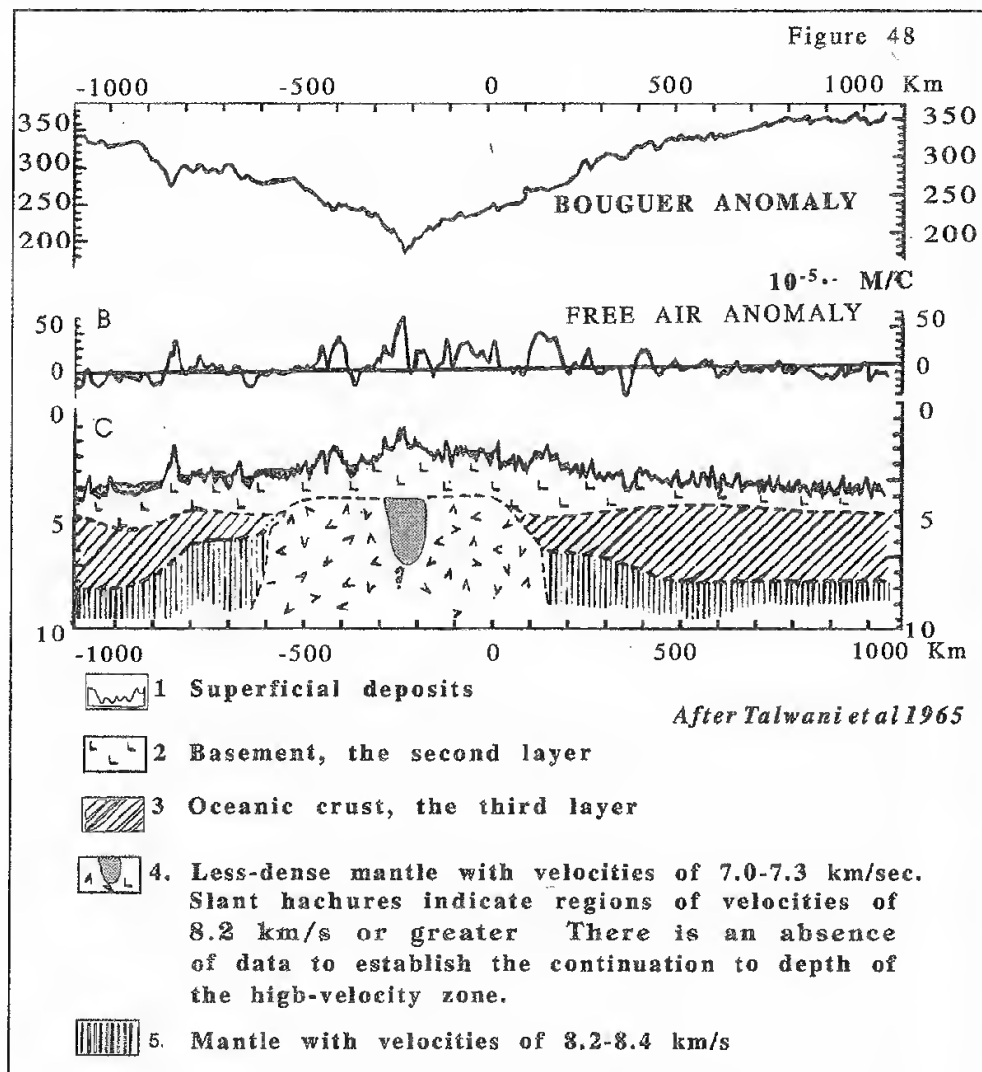
With increased distance from a ridge axis, the heat flow decreases (by an order of magnitude). It is very likely that all the aforesaid phenomena

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[4] *For magnetite the Curie point falls at 578°C. Admixtures of titanium, magnesium, and aluminum, which are usually contained in natural magnetites, significantly lower the Curie point.*

have a single cause. But it seems absurd to relate the drop in magnetic susceptibility to the cooling of matter, because the relationship of this characteristic to temperature is an inverse one. We are left, then to suggest the presence of a magnetically active substance in the axial zone of the ridge. This substance must degenerate in the course of spreading so as to induce the notable decrease of magnetic susceptibility and heat flow. It is virtually impossible to explain all these geophysical phenomena proceeding from the assumption that the mantle is wholly silicate in composition.

Our model, by presupposing the ascent of the metallic mantle in the ridge axis, allows the following interpretation of the geophysical features. Intermetallic compounds (silicides) is a term referring to semiconductors, which by their physical properties, are an intermediate class between typical metals and typical dielectric compounds. Their properties arc related to partial preservation of the metallic bond along with the establishment of an ion-covalent bond in the course of chemical interaction between silicon, on the one hand, and magnesium, iron, and other metals on the other. In particular, the thermal conductivity of silicides is approximately an order of magnitude higher than that of silicates. Thus, the ascent of silicides into axial regions of ridges permits abnormally high conductivity. Observed high heat flow is not necessarily a consequence of anomalously high temperatures in the axial interior of a ridge, because geothermal gradient is inversely proportional to thermal conductivity.

Simple calculations show that in the case of a silicate composition for the crust-mantle mixture and a heat flow of 420 mW/m^2, the geothermal gradient will be approximately 150°C/km, and thus, the temperature will already exceed the Curie point at less than two or three kilometres depth (Table 11). However, if the mantle in the axial zone is composed not of silicates but of silicides, intermetals, that is to say, the thermal conductivities of which are approximately an order of magnitude higher, the geothermal gradient accordingly decreases by an order of magnitude. For example, the temperature of 700°C, which corresponds with the Curie point for the iron - silicon alloy[5] will be reached at a depth close to twenty kilometres (Table 11). Therefore, in the case of a silicide (silicon-metal) composition of the crust-mantle mixture, which has been injected, diapir-like under the bottom of median rift valleys, the high heat flow of the axial zone of the ridge should develop a strong magnetic anomaly.

However, as silicides transform into silicates, thermal conductivity and magnetic susceptibility sharply decrease. In this light it becomes clear why the heat flow diminishes and the magnetic anomaly weakens in the course of ocean-floor spreading. Spreading is accompanied by silication of the intermetallic compounds intruded along the ridge axis.

Thus, according to our model, the abnormally high heat flow and the

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[5] *The Curie point for pure iron is fixed at 770°C. A silicon admixture lowers it to 700°C. A cobalt admixture elevates it significantly.*

axial magnetic anomaly of the median part of a ridge are believed to be related to the diapirism of intermetallic silicides from the deep mantle to near-surface horizons during ocean-floor spreading, which is caused by the Earth's expansion. The uneven development of silication is a function of the jet-like discharge of hydrogen, which causes it. Absence of the characteristic axial magnetic anomaly may characterize those places where silication has gone to completion.
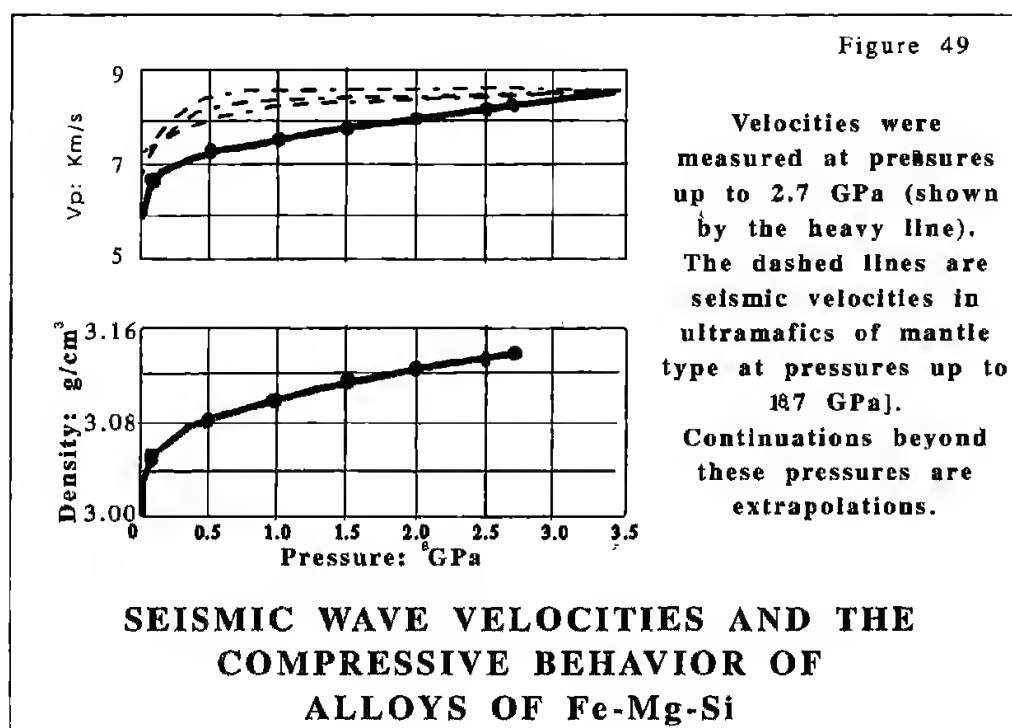
An experiment was run to interpret the gravimetric data of oceans and the mantle velocity profile. An alloy was prepared in which silicon, magnesium, and iron were mixed in the terrestrial proportions as determined by magnetic separation (Table IV).[6] As this composition corresponds to no less than 90 weight percent of the composition of the intermetallic mantle, the alloy was expected to correspond fairly closely to the crust-mantle mixture in density and seismic wave velocity.

TABLE 11		
VERTICAL RANGE OF MANTLE FERROMAGNETISM BELOW RIDGE AXES FOR VARIOUS COMPOSITIONS		
CHARACTERISTICS	*SILICATES*	*SILICIDES*
Heat flow: mW/m^2	$4.2 \times 10^{-5}_{-2}$	$4.2 \times 10^{-5}_{-1}$
Thermal conductivity: W/cm-K	2.9×10	1.2×10
Geothermal gradient: K/km	145	35
Curie point: °C	NATURAL MAGNETITE 350	Fe-Mg-Si ALLOYS > 700 >
Depth Ranges of Ferromagnetism: Km	2.5	20

The compressibility of the sample and its seismic wave velocities in a range of pressures up to 2.7 GPa (Figure 49) were determined at the high-pressure laboratory of the Institute of Physics of the Earth of the Russian Academy of Sciences. According to the results obtained, the density of the alloy is 3.06-3.07 g/cm^3 and the velocity is 7 km/sec within the pressure range of 0.20-0.25 GPa, which corresponds to the depth of 6-7 km, the approximate top of the crust-mantle mixture in some mid-ocean ridge localities. These characteristics increase with depth. The density reaches 3.1 cm^3 and seismic wave velocity is 7.6 km/sec under pressure of 1.1 GPa (i.e., approximately at a depth of 35 km), values that correspond closely with the density and seismic wave velocities of the crust-mantle mixture. However,

[6] *The alloy contained 51 wt-% silica, 35.5 wt-% magnesium, and 13.5 wt-% iron. The sample comprised metal powders; melting was carried out in an Alundum melting pot of an electric vacuum furnace.*

there are some reflectors within the lens of crust-mantle mixture that are characterized by much-increased boundary seismic velocities ranging from 8.0-8.2 and up to 9 km/sec (Vinogradov et al. 1972). From our point of view, such increased velocities result from hydrogen flows in the lens of the crust-mantle mixture. These flows cause change in the physical properties of metals. As metals are saturated with hydrogen, they all, without exception, lose elasticity and gain plastic deformability. Hardness increases along with brittleness and rigidity. For example, iron saturated with hydrogen scratches glass and may be crushed into a fine powder (Galaktionova 1967; and others). The resultant change of physical properties is accompanied by an increase in Young's modulus, which consequently implies that seismic velocities should increase in hydrogen-saturated metals (and alloys).

Figure 49

Velocities were measured at pressures up to 2.7 GPa (shown by the heavy line). The dashed lines are seismic velocities in ultramafics of mantle type at pressures up to 1&7 GPa]. Continuations beyond these pressures are extrapolations.

SEISMIC WAVE VELOCITIES AND THE COMPRESSIVE BEHAVIOR OF ALLOYS OF Fe-Mg-Si

Seismic velocities in silicides are lower than those in mafic-ultramafic rock and eclogites (Figure 49). That is why our model assumes a low-velocity channel in the seismic profile of the oceanic mantle, and why this channel is remarkable in that its upper boundary clearly defines the base of the silicate-oxide shell, whereas its lower boundary is absent. Because the base of the silicate-oxide shell gradually descends away from the ridge axis and toward the continents, the waveguide should descend in the same fashion. The waveguide comprises the silicate/silicide boundary, and as it descends, seismic wave velocity should incrementally decreases as well. These anticipated features of the seismic profile of the oceanic mantle exist in reality. Leeds et al. (1974), working in the Pacific basin, have identified the low-velocity channel with the asthenosphere using an analogy to continental mantle structure.

Figure 50

GEOLOGICAL TIME: x10⁶ Years

160   120   80   40   0

LITHOSPHERE
(Silicates)

ASTHENOSPHERE
(Silicides)

DEPTH: Km

0   50   100   150

THE REGULARITY OF DESCENT OF THE LOW VELOCITY ZONE WITH DISTANCE FROM THE MID-PACIFIC RISE

Data are from Leeds, Knopoff, & Kausel, 1974. Bracketed items represent our interpretation.
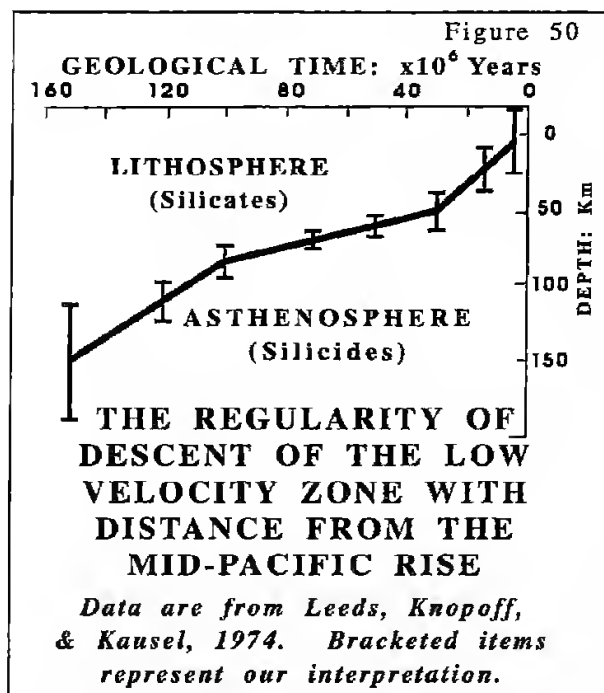
In addition, Leeds and co-authors, without going into details, draw attention to the possible absence of the low-velocity channel in the oldest parts of the ocean, where lithosphere thickness reaches 120 km and more. It is our opinion that the gradual disappearance of the wave-guide as the silicate-oxide mantle base gradually deepns may be explained as an equalization of seismic velocities in silicides and silicates with increase of pressure. Extrapolation of the curves beyond the limits of experimental data shows a parity between the seismic velocities in silicides and silicates (mantle eclogites) under pressures on the order of 3.4-3.5 GPa (Figure 49). These pressures correspond to the 120-km depth at which the waveguide becomes blurred.

An interesting seismic study of the deep structure of the North Atlantic median ridge (Francis 1969) shows a clearly defined anomaly in the ratio of pressure wave velocity to secondary wave velocity. The ratio in most places exceeded that in silicates, varying within the range of 1.92 to 2.56. This range is characteristic of metals (Press 1969).

Other interesting geophysical data include peculiar magnetic field anomalies on Atlantic-type transitions from continent to the ocean. Some workers ([Bennett & Liliey 1971)] attribute these anomalies to conductive mantle material ascending from the ocean side upward in scarp-like sutures. Our scenario interprets a scarp bordering the silicate buffer in the mantle along the continent-ocean margin (Figure 46). Then, with jet-like streams of inflowing hydrogen uneven silication results. This scenario should leave blocks of unoxidized or incompletely oxidized intermetallic compounds. The presence of the highly-conductive admixture in the silicate buffer explains the high electrical conductivity of the newly-formed mantle layer and may be the cause of the coastal geomagnetic anomalies.

Thus, we have derived from the hypothesis of the primordially hydridic Earth an interpretation of the origin and deep structure of the ocean floor that allows for non-contradictory interpretations of known geophysical properties. It is also to be noted that the comparison between densities and seismic velocities in the crust-mantle alloy mix that was

made with a composition determined by magnetic separation has proved significantly confirmatory of our concept.

8.4 Oceanic ores

The first finds of ore nodules from the deep-sea oceanic basins date back to the late 19th century. However, it has become clear only in the 1960s that oceans are rich in metals. Deep-sea oceanic oozes are significantly enriched in many ore elements, and the concentration of valuable metals is still higher within the pelagic limits, where iron-manganese nodules cover the ocean floor. The nodules occur below the level of carbonate compensation, where sediments are not diluted with carbonate materials (Table 12; Skornyakova & Andrushchenko 1970). Nodules form rich ore bodies in many abyssal basins, and the reserves of metals in the top one metre of their bottom sediments exceed by tens, hundreds, and thousands of times the world resources of copper, nickel, cobalt, and manganese on the continents (Menard 1966). Interlayers enriched in such nodules have not once been found in sediments when drilling below the ocean floor (Bezrukov 1971), which enlarges (probably by an order of magnitude) the reserves of metals that probably reside on the ocean floors and also evidences that there are more and less favorable epochs of ore formation and deposition in their geological history (Skornyakova & Andrushchenko 1970).

Basins filled with hot ore oozes were discovered on the Red Sea bottom in the 1960s. The largest of them (Atlantis-II) has the near-bottom layer 200 m thick and the temperature exceeding 56°C. Its salt concentration reaches 27%, in contrast with the salinity of the Red Sea at 4%. .According to the description by G.N. Baturin, those are semi-fluid oozes of bright coloring, containing more than 50% H_2O and NaCl. Having gone through washing and drying, they become an ore concentrate containing up to 45% iron, 25% manganese, 10% zinc, about 3% copper, 300 g/ton of silver, and 5 g/ton of gold (Baturin 1970). This unique discovery triggered the search for analogous mineralization in other parts of the global rift system. A series of ore-grade iron-manganese-carbonate sediments with the abundant admixture of lead, zinc, copper, and other elements were discovered on the crests of the East Pacific Rise and the Central Indian Ridge (Bostrom & Peterson 1966, 1969; Baturin 1971; Bezrukov 1971; and others).

Thus, the ore resources now known to exist in the oceans surpass by an order (and perhaps by many orders) of magnitude the world reserves of all metal deposits on the continents. Furthermore, study of the oceans has just begun, and the valuation of their ore reserves will evidently rise in the future.

The ore material of the oceans was originally believed to be derived entirely on erosion from the continents, either in solution or suspension. However, as the vastness of these ore reserves became evident and their tendency to be maximized at ocean-floor sites farthest from continents became apparent, a suspicion arose that the concentration of minor elements in bottom sediments is too high to be explained as derivatives from the

continents (Coldberg & Arrhenius 1958). This suspicion gained credibility by geochemical balance calculations (Wedepohl 1960; Arrhenius 1963).
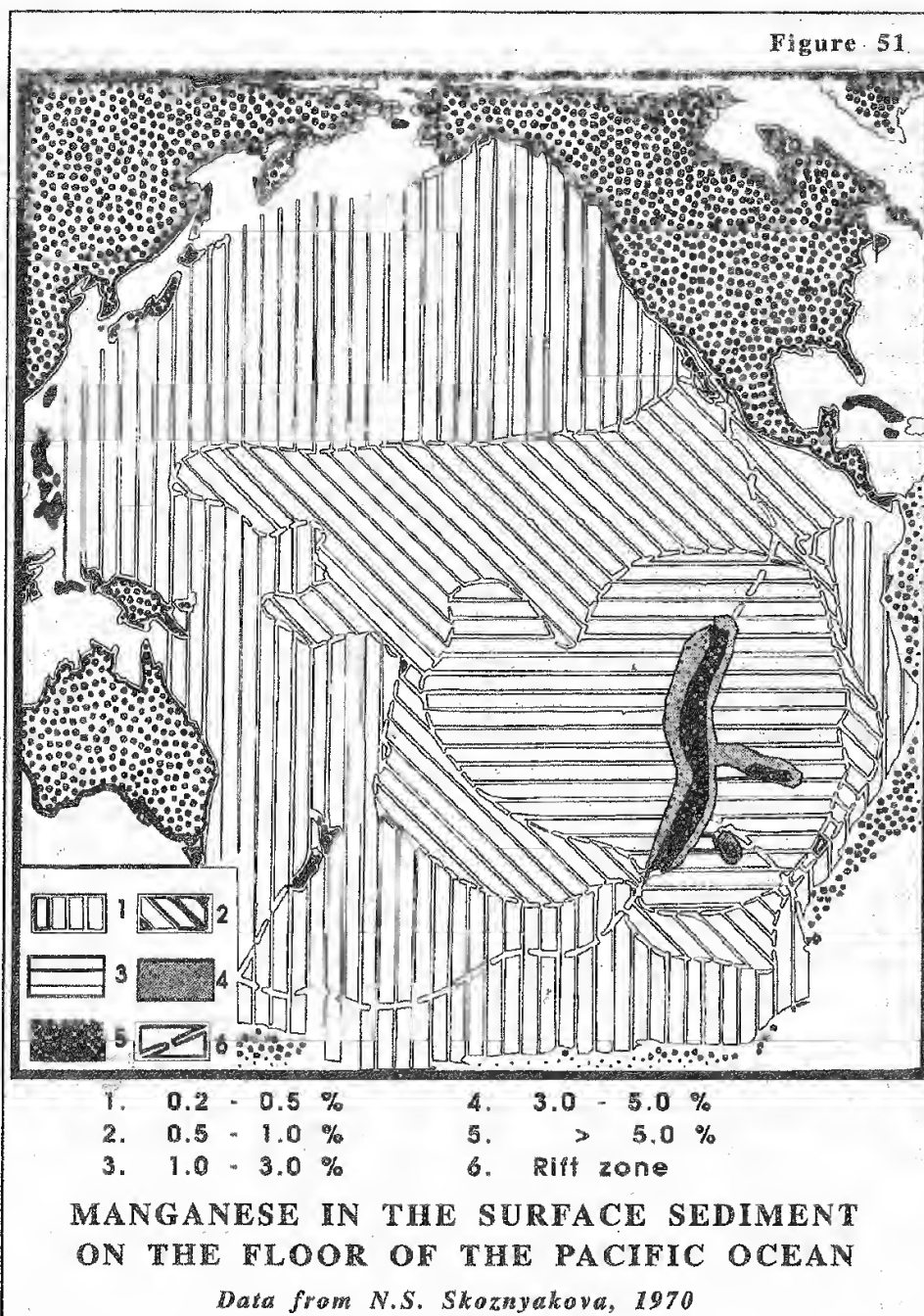
TABLE 12

METALS IN PACIFIC OCEAN SEDIMENTS

ELEMENT	1	2	3
MANGANESE	0.085	0.67	21.10
IRON	4.83	6.5	12.00
COBALT	0.0013	0.011	0.31
NICKEL	0.0053	0.030	0.67
COPPER	0.0048	0.040	0.43
ZINC	0.0095	0.020	0.71
MOLYBDENUM	0.0001	0.0046	0.04
LEAD	0.002	0.011	0.10

Notes: *(1) Modern, marine clay shales*
(2) Deepsea oozes
(3) Concretion

The enrichment of bottom oozes was then considered to be related to the supply of metals through volcanic exhalation. This possibility appeared natural, because the formation of ocean basins is accompanied by vigorous volcanic activity, particularly in the Pacific Ocean. However, a special geochemical study in the Pacific Ocean has shown the absence of any genetic relationship between ore and the effluents of volcanic emissions (Cherdyntsev et al. 1971; Lisitsyn et al. 1975). Moreover, maps of dispersion halos of iron and manganese (Skornyakova 1970) and many minor elements (Bostrom 1971) in bottom sediments show that the source of these metals is not in the central Pacific, where active volcanism is observed, but in its southeastern zone, which is not characterized by intense volcanic activity. Indications from maximal concentrations of these various metals are that the median part of the East Pacific Rise is a "metal-bearing" zone stretching along the subequal ridge axis for thousands of kilometres (Figure 51). This zone is a bountiful source of metals, providing vast areas with colossal ore reserves.

Figure 51

1.	0.2 - 0.5 %	4.	3.0 - 5.0 %
2.	0.5 - 1.0 %	5.	> 5.0 %
3.	1.0 - 3.0 %	6.	Rift zone

MANGANESE IN THE SURFACE SEDIMENT ON THE FLOOR OF THE PACIFIC OCEAN

Data from N.S. Skoznyakova, 1970

According to the opinion of K. Bostrom (1971), the geochemical maps for the Indian and Pacific Oceans allow the assertion that the eoncentration of iron, manganese, and some other elements is maximal in those parts of the ridge where the maximal rate of spreading is observed. This conclusion is confirmed by the study carried out by a group of Russian scientists who have shown that the amount of ore material on the ocean floor is directly proportional to the tectonic activity of the region (Lisitsyn et al.). Somewhat earlier it was shown that maximal eoncentrations of iron and manganese in recent

was shown that maximal concentrations of iron and manganese in recent sediments of the ridge are related to the zones of the most intense heat emission (Bostrom & Peterson 1969). The results of a complex mineralogical-geochemical and isotopic study of ore materials in the Pacific basin made it possible to relate ore genesis with the process of formation of new oceanic crust in the axial zone of a ridge (Dymond et al. 1973). However, basalts that are spatially associated with ore sedimentation do not, as a rule, display either signs of hydrothermal change or high concentrations of metals (Ross et al. 1973). Consequently, the source of ore material is not connected directly with magma generation and must have a different nature.

At present, the information available is insufficient to classify in temporal terms the distribution of ore materials in the oceans. The data obtained seem to be indicative of the fact that the enormous ore resources supplied to the oceans, as typified by the recent stage, started in the late Cretaceous or possibly early Cenozoic time, when the system of tectonically-defined mid-oceanic ridges appeared.

So we have seen that certain metals are emitted in great quantity during the process of expansion of oceans, especially in relation to mid-oceanic ridges. This phenomenon is so significant that it needs to be discussed in terms of any concept presupposing a global view of the geological evolution of the Earth. It should be noted that none of the ore-forming processes known at present can be considered responsible for the phenomenon in question. To explain these virtually inexhaustible resources, one is obliged to impute a grandiose source, one which is by many orders of magnitude larger than all known ore sources on the continents.

For this purpose we propose considering a process of silication as a possible source of the ore materials in oceans. This process involves intermetallic silicides in the interiors of mid-oceanic ridges. These intermetallic compounds preserve some substantial part of the metallic bond, and hence are capable of forming various alloys as well as solid solutions. For that reason the silicides of magnesium, iron, and other intermetals are able to retain in their lattices large admixtures of various other metals (and probably of metalloids as well: phosphorus, carbon, sulphur, etc.). Silicates, on the contrary, do not form alloys with metals, and their ability to form solid solutions is substantially inhibited. The rigidity of the Si-O bond prevents the formation of intrusive structures; and the cation-anion character of the crystal matrix in many cases restricts substitution between elements of comparable atomic radii, by the incompatibility of outer electron shell structures with electronegativity. Hence, the isomorphic capacity of silicate crystal lattices is rather small.

The regeneration of silicides into silicates must therefore be accompanied by the evacuation of most other elements. This process releases a large number of "extraneous" (non-petrogenetic) metals and, probably, metalloids as well, because they are not capable of substantial isomorphic substitution in the silicon-oxygen lattices.

Oceanic ores exhibit quite remarkable compositions. Their siderophilic elements are iron, manganese, cobalt, nickel, and vanadium. Their chalcophilic elements are zinc, copper, lead, silver, and gold. In oceanic sediments their main ore components are represented by the elements that have small affinities for oxygen, a fact which cannot be regarded as mere chance, because silication delivers, first of all, those elements whose oxygen bond energy is low, when oxygen is first available for reaction.[7]

According to our model, the supply of ore material to the planetary surface should be fully manifest as late as the mature stage of ocean evolution. At this stage the median ridge has formed and the regeneration of intermetallic compounds into silicates goes on under near-surface conditions directly beneath the rift valley bottom. At first the zone of silication is situated at a depth of more than 100 km and is hidden below the asthenosphere, which prevents persistent zones of tectonic weakness from becoming ore-bearing structures. Hence, ore manifestations gradually diminish downward in the sedimentary oceanic sequence. Consequently, drilling in oceans can reveal rather distinct time boundaries for each ocean, above which deposited ore is constantly a member of sedimentary sequences, while below the boundaries ore diminishes. It should be noted that these boundaries are apt to be closely dated to the emergence of tectonically-defined mid-oceanic ridges. Verification of this prognosis has a practical application, for if it is confirmed, the metallogenic concept of ore generation in fold belts (Cimmerian, Hercynian, etc.) will have to be revised.

Our concept considers the ore material of oceans the "waste products" of silication of intermetallic compounds. The mineral composition of the newly-formed silicate buffer has been explained (Chapter VII, 2). Subsequent serpentinization evidently does not influence the distribution of the admixed elements remaining in silicates (Vinogradov et al. 1972). Furthermore, the scale of serpentinization is not comparable to the volume of silicides transformed into silicates. The ascent of metallic mantle into the oceanic median zones is a global process controlled by the Earth's expansion, so that the enormity of the metal resources of the oceans should not be thought of as something extraordinary. The foregoing considerations allow the statement that the Red Sea hot-ore oozes, while likely unique, are not exceptional, and that analogous, unconsolidated mineralization should be discovered in unique settings in the axial parts of median ridges elsewhere. The prospecting for such resources will likely increase in future. Finally, based on geophysical data, intermetallic compounds themselves occur below continental sites, in

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[7] *Let us explain this thesis by a simple example. Nickel and aluminium form the intermetallic compound NiAl melting at 1 640°C without dissociation. It is noteworthy that the interaction of these metals at 1 300°C is explosive. However, if oxygen is active enough, the reaction $NiAl + O_2 - Al_2O_3 + Ni$ will take place because the affinity of aluminium for oxygen: its oxygen bond energy being much higher than that of nickel.*

some places at depths of no more than several kilometres, where prospecting is feasible.

It should be mentioned that a difficulty occurs in explaining how to accommodate the comparatively shallow occurrence of oxygen-free compounds and alloys and their absence from oceanic sediments. Furthermore, the axial zones of ridges are characterized by active volcanism under which individual fragments of metallic debris might be expelled to the surface and remain for some time in sediments under conditions favorable for preservation. In this connection, the discoveries of native metals, including aluminium, in mid-ocean ridge sediments becomes cardinally important (Shterenberg & Vasil'eva 1979; Butuzova et al. 1987). The fact that in these finds aluminum prevails (with various metal-silicon inclusions) can be explained by the protective properties of the oxide film (Al_2O_3), which is resistant to the environment. Whereas these discoveries obviously are astonishing from the traditional point of view, whereas they are in concert with our concept.

8.5 Metallogenic aspects of rift zones on the continents

We should also discuss the possible ore manifestations in the rift zones superimposed upon the continents. It has been shown above that at the rift stage the asthenosphere spans the zone of silication and acts as a shield in two ways. First it prevents fractures in the overlying brittle crust from propagating themselves downward. Second, it blocks the escape of fluids from below. Asthenosphere cannot be a 100% effective shield, however. An area where it has failed to retain the underlying fluids is the Red Sea, where ore-grade mineralization is an ongoing phenomenon. In addition, the intermetallic diapirs are likely to be capable of reaching the supra-asthenospheric horizons in some places in the form of individual tongues at the rift stage. This interpretation is confirmed by the existence of traces of anomalously high mantle electroconductivity at depths usually of 30 to 50 km, but sometimes 20 to 25 km, or even as little as 10 km in rift zones. It is noteworthy that the character of the heat flow does not provide grounds for considering the phenomenon of high conductivity as products of the abrupt ascent of the geo-isotherms (Rikitake 1972). Consequently, rift zones on continents are implicitly good prospects for the entire complex of metals contained in the ores of the ocean basins. This extends to silver and gold, which dissolve in sea water and, hence are absent from ocean-floor sedimentary ores. Silication at depth enriches intratelluric fluids with ore components, which then may form ore deposits in the upper horizons of the crust under favorable structural-lithological conditions.

On this subject, attention was paid to the USA western regions under which the East Pacific Rise "disappears," thus causing rifting over a vast area. The area involved in rifting has a number of specific features of deep crustal and mantle structure. Low seismic velocities (7.8 instead of 8.1-8.2 km/sec) have been discovered in the mantle beneath the mountain regions in the western USA. This implies some mantle decompaction (Herrin 1972).

Crustal thickness is only 30 to 40 km here; and consequently, isostatic compensation does not apply to the "mountain roots," as in typical fold belts. The elevated relief of the subject area is likely to be related to mantle decompaction, as with typical mid-ocean ridges. The western USA geological province displays high heat flow and indications that the source of the excess heat is in the upper mantle rather than the crust [Simmons, Roy, 1971]. Finally, the pattern of seismicity of this region, according to some experts (Woollard 1972) is similar to that of the East Pacific Rise. These enumerated facts allow a conclusion that the East Pacific Rise, in diving under the US western regions does not disappear completely; and the processes characteristic of a median ridge continue at great depth beneath the continents. As a matter of fact, the above geophysical data corroborate our model of ocean floor formation, because they are evidence for the ubiquitous deep-seated mechanism behind the formation of oceans at all stages. This conclusion leads us in turn to anticipate the prospects for ore (as "waste products" of the silication of silicides) in the continental rift zones in the manner of ores in ocean basins.

In this connection, the Cenozoic gold-silver and polymetallic (lead, zinc, copper) deposits of the hydrothermal-metasomatic type in the western USA are of interest (Ore ... 1972). These deposits are involved with rifting. They occur in Utah, Colorado, Nevada, Idaho, and Montana. One of their distinctive features is a persistent content of iron and manganese, which is expressed in the prevalence of siderite and its manganese variety, manganosiderite, as well as rhodochrosite and rhodonite among gangue minerals in the veins. Several huge metasomatic bodies of pure rhodochrosite were discovered in the Montana region, and these are important source of manganese. In addition, the manganese gangue minerals in other mines are often of industrial interest as by-products. Some volumes among these metasomatic bodies and rhodochrosite veins shows that manganese has been replaced in carbonates by iron.

Our systematics allow us to make a prediction as to the relationship between these manganese- and iron-enriched ore deposits (of gold, silver, lead, zinc, and copper) and the silication of intermetallic silicides at depth in rift zones. The implication is clear from the outset that the subject mineralization coincides in time and space with the phenomenon of rift openings that split the geological province. In his foreword to the book "Ore Deposits of the USA" V.I. Smirnov (1972) noted "a clearly defined taste of its authors for the magmatogenic origin of ore deposits...." However, when describing the ore deposits, the authors of the book had to point to the absence of any direct genetic relationship between the ores and outcropping intrusions and to "suppress" their interpretations of sources for the metals to unseen horizons deep in the crust, where a center of magma generation or a batholith could have produced both the ore-bearing fluids and the plutons that are closely related to it in time and space.

For these situations our model allows us to affirm the hypothetical notion of a "deep center," identifying it with the tongues of deep-seated

diapirs of the intermetallic mantle. These diapirs have been intruded above zones of tectonic weakness into the subcrustal horizons where silicides under the influence of intratelluric fluids are transformed into silicates and enrich the ambient fluids with dissolved ore components. This interpretation, as distinct from the magmatogenic concept, neither requires huge magma reservoirs as a source of metals nor imputes the existence of such reservoirs at depth during the process of ore generation. Additionally, it is noteworthy that the presumed presence of batholiths below orefields is hardly concordant with the absence of the Miocene - Pliocene thermal metamorphism in the supra-intrusive terranes.

There is a great similarity between the Baikal rift zone and the western United States as to their deep structure. For instance, a geophysically anomalous zone has been found in the upper mantle in southeastern Siberia (Structure ... 1973). Its width varies between 200 and 400 km. Its seismic wave velocities are 7.7-7.8 km/sec, in contrast with normal velocities (8.1-8.2 km/sec) in adjacent areas. The anomalous zone in the mantle is wider than the rift itself, its southeastern border being at a distance of 200-300 km from Lake Baikal, where it underlies large, ancient geological structures. The Baikal rift is situated above the northwestern edge of the anomalous zone. The striking resemblance between upper mantle seismic profiles under the Baikal rift zone and under the Basin and Range province of the western USA has been noted by Krylov and others. (1975). The rich ore mineralization of Cenozoic age, which in our opinion is related to rifting, suggests that the Baikal rift area could have mineralization similar to the Cenozoic orefields of the western USA, all of it the result of the intrusion of intermetallic diapirs and their silication.

CHAPTER IX

ISOTOPE GEOCHEMISTRY AND THE NEW MODEL OF THE EARTH.

The correlation previously described between abundances and ionization potentials of elements of the Solar system leads to a quite different interpretation of the available data on isotope geochemistry. In this connection the uranium-lead, samarium-neodymium, and rubidium-strontium decay systems as well as some characteristics of helium isotopes and some data on stable oxygen isotopes are considered. An emphasis is placed on recently discovered paradoxes of isotope geochemistry and on the possibility of accounting for these aberrations by the new Earth model.

This book is designed for the widest possible readership, including those without insight into isotope geochemistry. All relevant data are presented in the most condensed form that suffices for critical evaluation in the discussion.

Isotope geochemistry of radioactive elements and their radiogenic products is based on the law of radioactive decay,

$$N_t = N_0 \exp(- \lambda t), \qquad (1)$$

where N_0 is the original amount of parent isotope, N_t is the amount of the same isotope at a moment of time T after the "beginning,"[1] λ is the decay constant of fixed value for each radioisotope. In physics, the decay constant is a function of the half-life of the isotope in the following way: If $T_{0.5}$ is the time interval during which exactly one-half the parent isotope decays, i.e., at

$T_{0.5}$, $N_T = N_0/2$, and the law of radioactive decay can be rewritten as

$N_0/2 = N_0 \exp(- \lambda T_{0.5})$, or, after some transformations, as

$\exp(- \lambda T_{0.5}) = 2.$

In the logarithmic form, the law can be written as

$\lambda T_{0.5} = \log_e 2 = 0.693...,$

or as $T_{0.5} = 0.693/\lambda.$

9.1 The conventional approach and its inherent paradoxes:

The rubidium-strontium isotope system

Radioactive isotope ^{87}Rb decays to daughter isotope ^{87}Sr emitting a beta-particle and a neutrino,

$$^{87}Rb = {}^{87}Sr + \beta + v + 0.275 \text{ Mev.}$$

For ^{87}Rb, the $T_{0.5}$ is estimated as $(5.0 \pm 0.2) \, 10^{10}$ years, and the decay

---

[1] *The beginning is a moment of evolution of a system, since which the sum of parent and daughter atoms is a constant; in other words, it represents a moment of time, after which a system is closed to further isotope exchange.*

constant, λ, is $1.39 \cdot 10^{-11}$ (years)$^{-1}$.

The number of atoms of daughter isotope D is the difference between the initial number N_0 of atoms of parent isotope, and the number of atoms N_T of the same isotope at a particular moment of time,

$$D = N_0 - N_T. \tag{2}$$

The equation (1) can be re-written as $N_0 = N_T \, e^{\lambda t}$. $\tag{3}$

Substituting (3) into (2), one obtains

$$D = N_T \, e^{\lambda T} - N_T = N_T \, (e^{\lambda T} - 1). \tag{4}$$

For the rubidium-strontium isotope system, (4) looks like

$$^{87}Sr = {}^{87}Rb \, (e^{\lambda T} - 1), \tag{5}$$

where ^{87}Sr is the amount of radiogenic strontium accumulated in the system during the interval T, and ^{87}Rb is the amount of parent rubidium left in the system at the end of the interval T.

However, it can certainly be stated that from the moment the isotope system was closed, and an observer had started to "watch" for the decay of radioactive ^{87}Rb and accumulation of radiogenic ^{87}Sr, some quantity of radiogenic ^{87}Sr was already in the system as the result of earlier events of nuclear-synthesis and decay. This strontium, which is usually regarded as "initial" and denoted as $^{87}Sr_0$, should be incorporated into equation (5) in order to correlate with natural conditions.

$$^{87}Sr = {}^{87}Sr_0 + {}^{87}Rb \, (e^{\lambda T} - 1) \tag{6}$$

In practice, it proved more convenient not to use isotope concentrations themselves, but the ratios normalized to the stable isotope ^{86}Sr, because its concentration in the system is constant. Also, in mass spectrometry, isotope ratios can be measured more easily than concentrations. Thus, after transformation, equation (6) is transformed to:

$$^{87}Sr/{}^{86}Sr = ({}^{87}Sr/{}^{86}Sr)_0 + ({}^{87}Rb/{}^{86}Sr) \, (e^{\lambda T} - 1). \tag{7}$$

In some cases, the following approximation can be used:

$$e^{\lambda T} = 1 + \lambda T + (\lambda T)^2/2! + (\lambda T)^3/3! + ... (\lambda T)^n/n!$$

The sum of the third and following members of this row is by three to four orders less than the sum of the first two members, and so

$$e^{\lambda T} @ 1 + \lambda T. \tag{8}$$

Applying this approximation to equation (7), one obtains:

$$^{87}Sr/{}^{86}Sr = ({}^{87}Sr/{}^{86}Sr)_0 + ({}^{87}Rb/{}^{86}Sr) \, \lambda T, \tag{9}$$

or

$$^{87}Sr/{}^{86}Sr = ({}^{87}Sr/{}^{86}Sr)_0 + (Rb/Sr) \, K\lambda T, \tag{10}$$

where

$$K = \frac{(\text{isotope concentration } {}^{87}Rb) \cdot (\text{atomic weight Sr})}{(\text{isotope concentration } {}^{86}Sr) \cdot (\text{atomic weight Rb})}$$

Several ideal phases, which originally had different Rb/Sr ratios, are plotted in $^{87}Rb/{}^{86}Sr$ versus $^{87}Sr/{}^{86}Rb$ coordinates (Figure 52). It is clear that originally, to be precise, at the time the isotope systems were closed, all plots should have fallen on a horizontal line, because no accumulation of radiogenic strontium could

yet have taken place. Thus, $^{87}Sr/^{86}Sr$ ratios for each plot must precisely have corresponded to the $^{87}Sr/^{86}Sr$ ratio in the reservoir at the moment when all phases were closed.

Figure 52
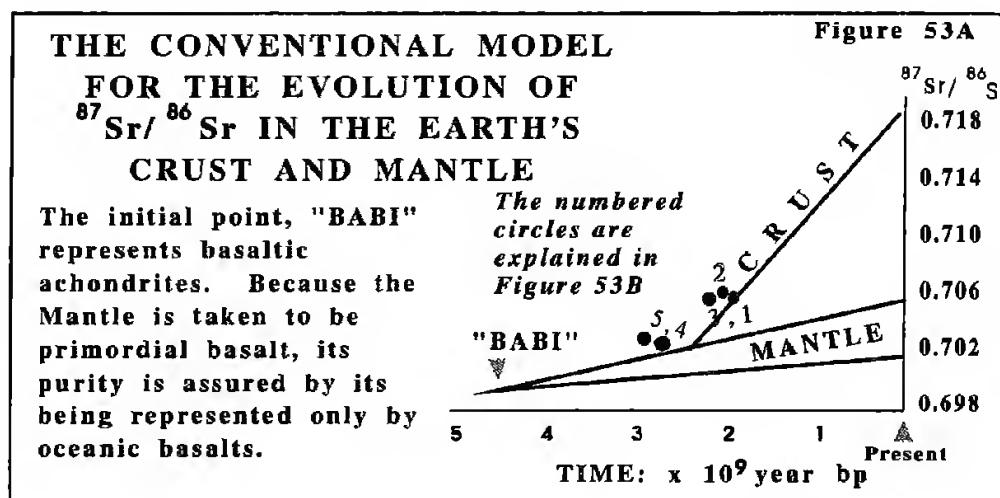
THE HYPOTHETICALLY ISOCHRONOUS RELATIONSHIP
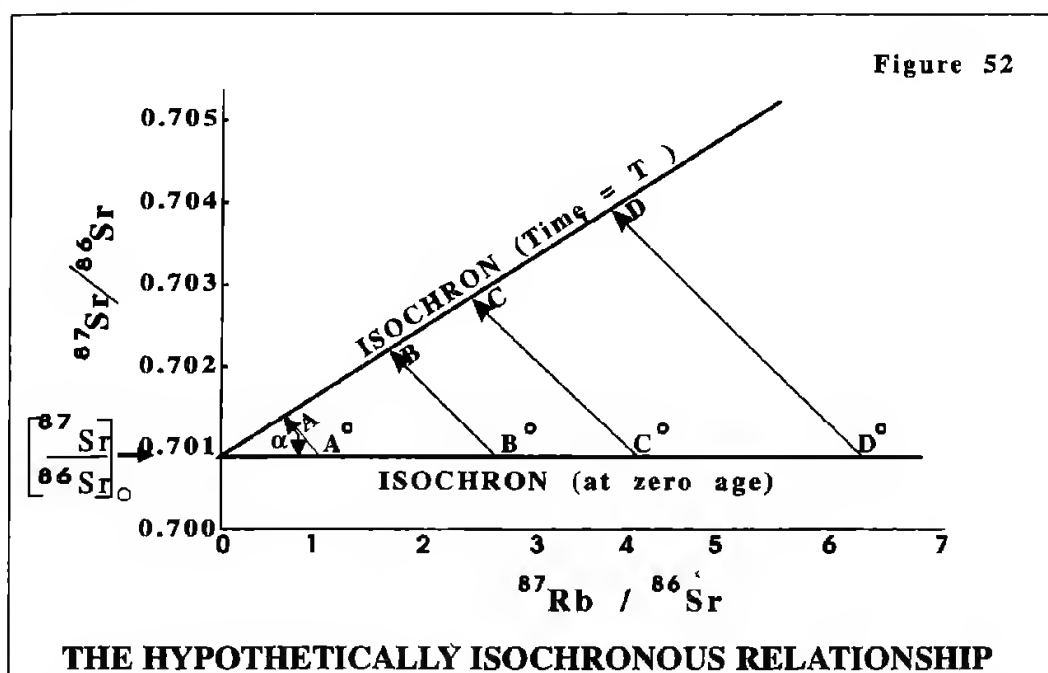
At a particular time T_1, these plots fall on a straight line passing through the same point on the Y-axis and inclined at an angle, "a" to the original horizontal line. This inclined line is an isochron, whereas the point at which it crosses the Y-axis, defines the "initial ratio", $(^{87}Sr/^{86}Sr)_0$. The angle "a," which depends on the time interval since the closure of these phases can be calculated. From any point on the isochron, one can draw two perpendiculars to the X- and Y-axes and thus determine corresponding present-day ratios of $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$. When these two ratios, together with the initial ratio, are known, equation (7) can easily be solved with respect to the only unknown parameter, T.

Data on the rubidium-strontium system are commonly presented as lines reflecting the evolution of $^{87}Sr/^{86}Sr$ ratio over time. In the traditional model for the evolution of the terrestrial crust and mantle (Figure 53a), the initial ratio for $^{87}Sr/^{86}Sr = 0.699$. This is derived from meteorites (basaltic achondrites). The slope of the plots (equations 7, 9, 10) depends on this Rb/Sr ratio. The larger the ratio, the steeper the line representing the evolution of the ratio with time. If a system is greatly enriched by strontium, and the rubidium concentration is low (for instance, in anorthosites), the addition of radiogenic strontium is so minute that the slope of $^{87}Sr/^{86}Sr$ evolution for this situation is nearly horizontal.

Values for crust- and mantle-derived rocks fall into definite trend lines that show their origins, but only for Rb/Sr ratios that have remained consistently close to average values in the crust and mantle. Actually, however, these ratios vary considerably both in the crust and mantle. Because the age of these variations

can be up to several billion years, certain Rb/Sr ratios commonly diverge far from the corresponding ideal trends.

Figure 53A

THE CONVENTIONAL MODEL FOR THE EVOLUTION OF ^{87}Sr/^{86}Sr IN THE EARTH'S CRUST AND MANTLE

The initial point, "BABI" represents basaltic achondrites. Because the Mantle is taken to be primordial basalt, its purity is assured by its being represented only by oceanic basalts.

The numbered circles are explained in Figure 53B

Most probably, in this situation, it will never be possible to test the validity of the proposed model with experimental data. There is hardly any doubt that Rb/Sr ratio is higher in the crust than in the mantle, because rubidium is a much more lithophilic element than strontium. Due to this factor, the evolutionary line of ^{87}Sr/^{86}Sr ratio for any sampling of the crust should be steeper than for any mantle sampling, as the model correctly predicts. Present-day ^{87}Sr/^{86}Sr ratios in the ancient crust can be determined, for instance, by studying river water in rivers which drain shields. These yield average values for large areas. By contrast, an estimation of Rb/Sr ratios in the modern mantle poses a great problem, because it is difficult to determine how much contamination of strontium from the crust has been introduced into mantle samples. Where ancient continental crust is absent, in the oceans, the "mantle field" in the model is bordered by lines which select a section of the Y-axis that embraces most ^{87}Sr/^{86}Sr values for oceanic basalts (from 0.702 to 0.706, and averaging 0.7037). If one uses ^{87}Sr/^{86}Sr = 0.7037, $(^{87}$Sr/^{86}Sr$)_0$ = 0.699 and T = 4.57 Ga, then, the average Rb/Sr in the mantle is about 0.025 (equation 10).

Hereinafter, it will be shown that such an approach for determining the average Rb/Sr ratio in the Earth mantle is invalid. Now, it is worth pointing to another clear contradiction, which has already been incorporated into the traditional model. According to this model, the mantle reservoir remained unaltered during the formation of the sialic crust. In other words, it made no "contribution" to the process of crust formation. This lack of alteration could have been true for a mantle having an infinitely large supply of rubidium by comparison with the crust. But it is clearly incorrect; and one has to assume a certain rubidium depletion of the mantle during crust formation. Because this depletion decreases the Rb/Sr ratio, the line of evolution for ^{87}Sr/^{86}Sr ratio in the mantle should have a flex point corresponding to the commencement of crust formation. Afterwards, the slope of the line of evolution should be gentler. This depletion has not in any way

been taken into account in the traditional model (Figure 53a).

EVOLUTION OF THE ^{87}Sr/^{86}Sr RATIO IN CONTINENTAL CRUST AND MANTLE UNDER THE NEW THEORY

Figure 53B
^{87}Sr/^{86}Sr

Line α-β represents the development of strontium isotopes in primordial mantle material ("hypolite"). Characteristically a "restite" comprising the transformed mantle reservoir after creation of crust 2.5 billion years ago. The restite line shows less slope because of rubidium escape from the mantle reservoir into the crust.

Some Precambrian mafic complexes that exhibit mantle origins include:

1. The Losberg intrusive (South Africa),
2. The Bushveld complex (South Africa),
3. The Nipissing diabase (Ontario, Canada),
4. The Stillwater complex (Montana, USA), and
5. The Ushushvana series (South Africa),

Data from Faure & Powell 1974

The position of these complexes of confirmed mantle origins within the framework of the new theory could be explained as blending of the "hypocite," the primordial mantle material. For the contrast with the traditional explanation, see Figure 53A, wherein the interpretations of their origins require extremely complex petrogenetic schemes.
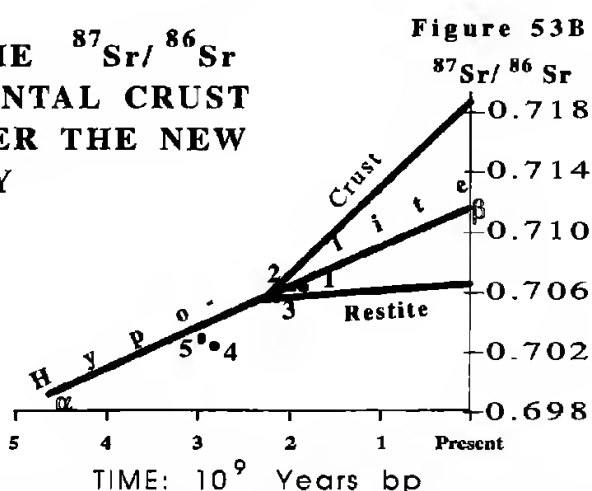
The samarium-neodymium isotope system

Seven isotopes of samarium and seven isotopes of neodymium are found in nature. Radioactive isotope ^{147}Sm decays emitting an alpha-particle: ^{147}Sm = ^{143}Nd + α + 2β + gamma + Q. The daughter isotope, ^{143}Nd, is stable. The half-life of ^{147}Sm is 1.06×10^{11} years, and the decay constant, $\lambda = 6.539 \times 10^{-12}$ years^{-1}. In similar fashion to Rb-Sr procedures, the ^{143}Nd/^{144}Nd ratio is used instead of the ^{143}Nd absolute-content value; isotope ^{144}Nd is stable, and its concentration is unchanging.

For the Sm-Nd system, a parameter e is conventionally used :

$$\varepsilon_{Nd} = 10^4 \times [(^{143}Nd/^{144}Nd \text{ sample}) /(^{143}Nd/^{144}Nd \text{ standard}) -1] \quad (11)$$

This parameter shows the deviation, in hundredths of a percent, of the sample from the standard. If a Sm/Nd ratio exceeds the standard, its evolution in time is positive; otherwise, it is negative.

It is worth noting that, for calculation of ε_{Nd} values, the initial $(^{143}Nd/^{144}Nd)_0$ ratios are used (i.e., those ratios which had existed in a rock or mineral at the time

of its formation). The initial ratio can be determined from the intercept on the Y-axis of the isochron value of this ratio. By contrast, if the age of a sample and the present-day ratios of $^{143}Nd/^{144}Nd$ and $^{147}Sm/^{144}Nd$ in a same sample are both known, one can determine the initial ratio from the equation:

$$^{143}Nd/^{144}Nd = (^{143}Nd/^{144}Nd)_0 + (^{147}Sm/^{144}Nd)(e^{lT} -1), \quad (12)$$

This is similar to (7). In each case the $^{143}Nd/^{144}Nd$ ratio of the standard is re-calculated for the moment for which the initial ratio was calculated.

For a standard, many researchers use the CHondrite Universal Reservoir, CHUR, which is characterized by the following parameters: the primary $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ ratios are 0.2027 and 0.505828, respectively, and the present-day $^{143}Nd/^{144}Nd$ ratio is 0.511836 [Jacobsen and Wasserburg, 1980]. The consensus is that CHUR parameters characterize Earth's primordial mantle.

Figure 54a
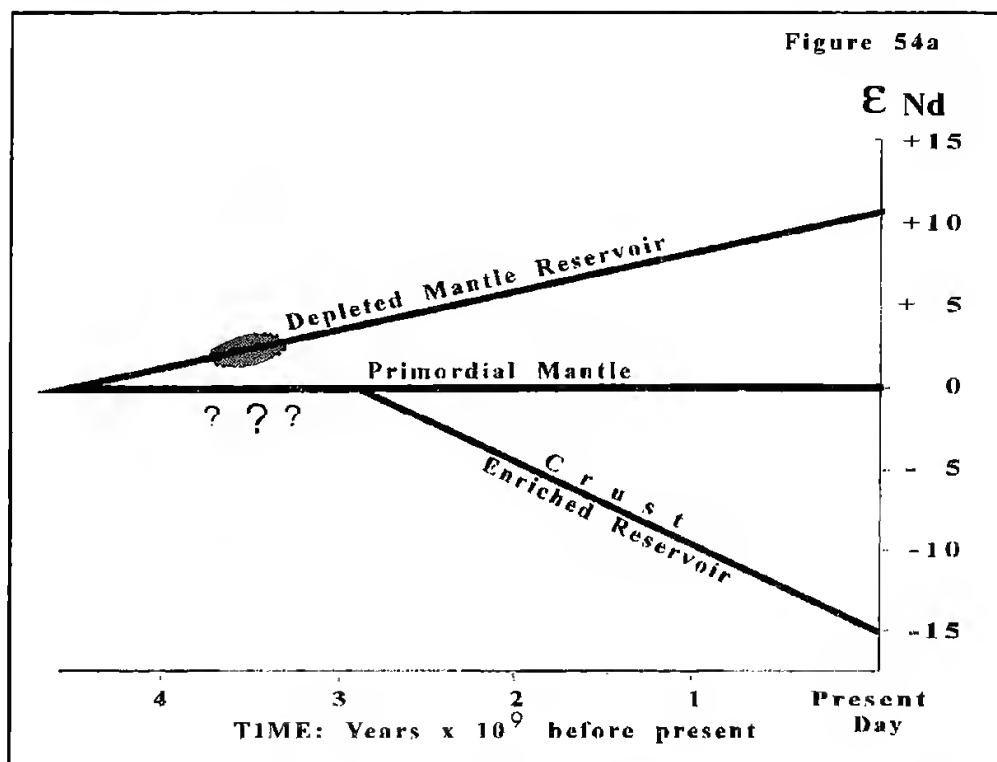
THE CONVENTIONAL MODEL FOR NEODYMIUM

Primordial mantle composition is taken to be synonymous with universal chondrite reservoir composition, "CHUR." It is important to point out that the earliest appearance of depleted reservoir conditions in the mantle preceded, by a long period, the first appearance of crust. The stipled area includes the zone of earliest planetary formation, which has traditionally been taken to have originated with depleted mantle. The question marks indicate the depositional sites where values are lodged in complementary enriched reservoirs.

The available data on the $^{143}Nd/^{144}Nd$ ratio evolution can be shown as

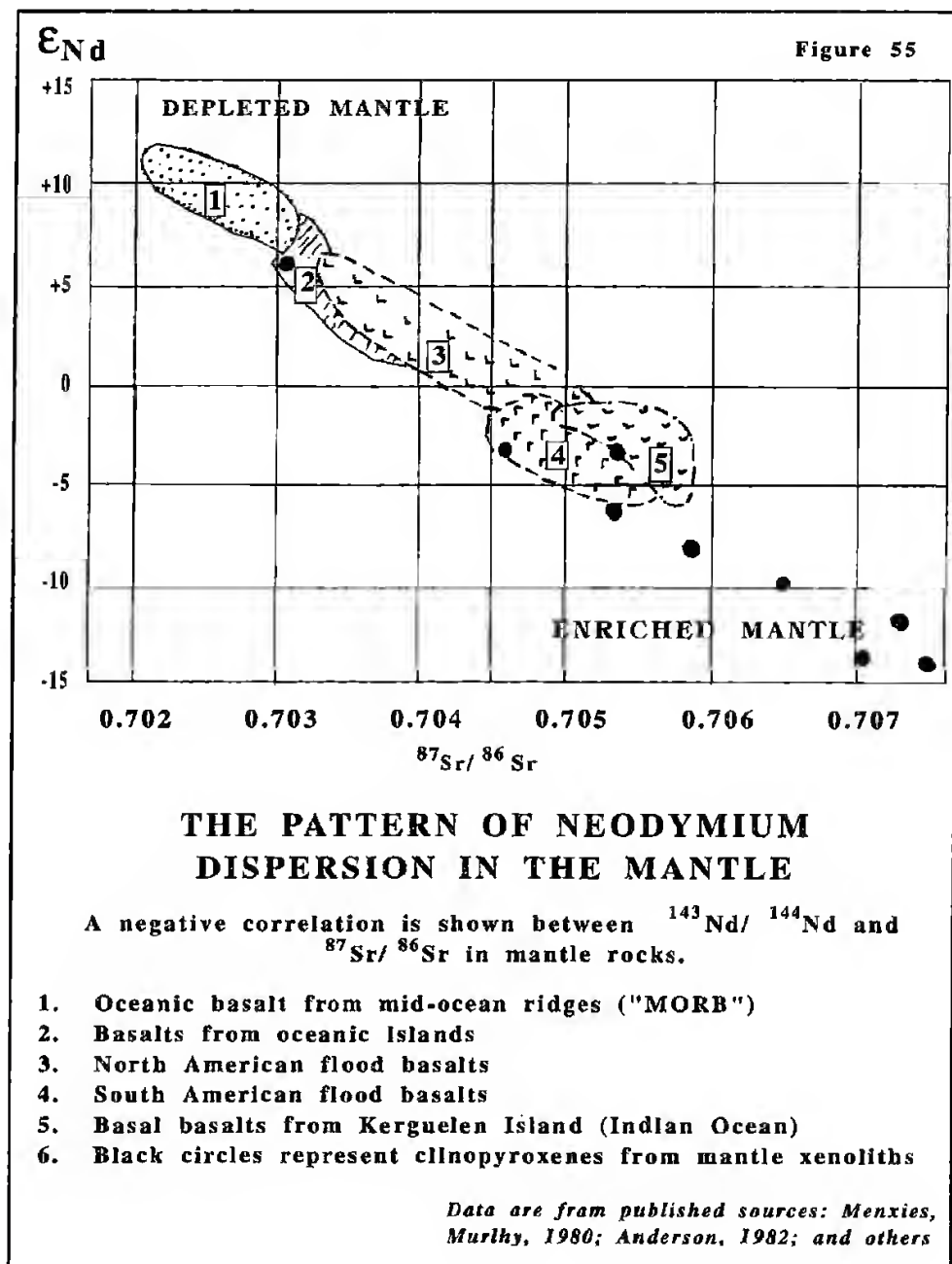generalized schematics (Figure 54a). Conventional notation represents positive and negative ε_{Nd} values in the Sm-Nd system as "depleted" or "enriched" sources, respectively. Because neodymium is more lithophilic than samarium, the crust is relatively enriched in neodymium with respect to samarium, and thus, crustal Sm/Nd ratios are smaller than mantle values. Therefore, ε_{Nd} evolves toward negative values in the crust.
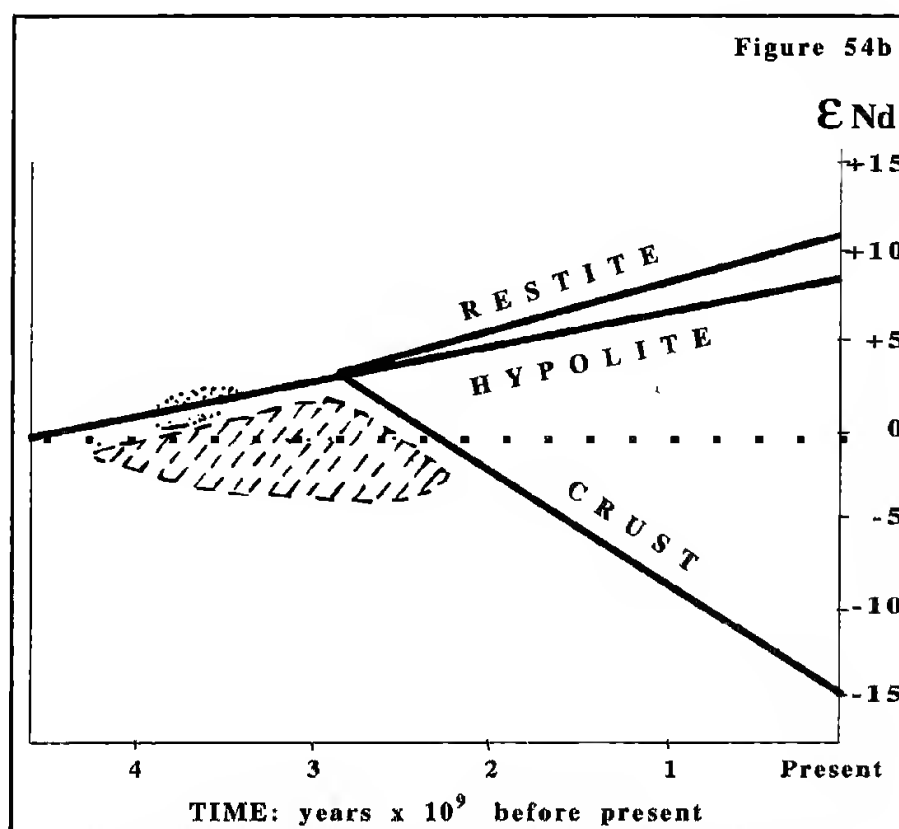
THE EVOLUTION OF NEODYMIUM (Nd)
ISOTOPES UNDER THE NEW THEORY

The ratio of Nd/Sm is a little higher here than in meteorites (CHUR). The crust and restite (depleted mantle) appear simultaneously. The most ancient planetary matter is indicated by the stipled area, the location of which, under the new theory, is on the level of the evolved primordial mantle, the "gypolite." The hachured area represents the absence of ε_{Nd} (the "forbidden zone") under the new theory.

THE PATTERN OF NEODYMIUM DISPERSION IN THE MANTLE

A negative correlation is shown between $^{143}Nd/\ ^{144}Nd$ and $^{87}Sr/\ ^{86}Sr$ in mantle rocks.

1. Oceanic basalt from mid-ocean ridges ("MORB")
2. Basalts from oceanic Islands
3. North American flood basalts
4. South American flood basalts
5. Basal basalts from Kerguelen Island (Indian Ocean)
6. Black circles represent clinopyroxenes from mantle xenoliths

Data are from published sources: Menzies, Murthy, 1980; Anderson, 1982; and others

It will presently be shown that the CHUR provenance is not identical to the mantle of primordial Earth. For now, a very intriguing problem justifies our attention. If the depleted reservoir had already existed 3.8 Ga ago, why was the appearance of the complementary enriched reservoir in the crust delayed a billion years (Figure 54a)?

Researchers have long since lost hope of finding negative ε_{Nd} values in the most ancient formations of the Earth, while easily-reproducible positive ε_{Nd} values are common in formations with ages around 3.75-3.85 Ga. This phenomenon can be identified as "the paradoxical lack of the negative ε_{Nd} values in the most ancient formations." Explanations that have been proposed to resolve this paradox have lead, as a rule, to geodynamic convolutions.

Recently, many studies have revealed a negative correlation between the $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios, the "mantle array" (Figure 55). The origin of this correlation is now under intense scrutiny. One hypothesis assumes an interaction between mantle melts and ancient sialic crust, the latter being characterized by low $^{143}Nd/^{144}Nd$ and high $^{87}Sr/^{86}Sr$ ratios (Figures 53a, 54a). The second explanation implies the existence of enriched and depleted mantle reservoirs (Figure 55). However, oceanic basalts are always regarded as derived from the depleted mantle reservoir, according to Rb-Sr and Sm-Nd systematics.

The uranium-lead isotope system

The isotopes of this system are tabulated as follows:

Parent isotopes	Half lives (years)	Radio-isotopes	Ratios measured
^{235}U	$7.04 \cdot 10^8$	$^{207}Pb + 7\,^4He$	$^{207}Pb/^{204}Pb$
^{238}U	$4.47 \cdot 10^9$	$^{206}Pb + 8\,^4He$	$^{206}Pb/^{204}Pb$

The isotope ^{204}Pb is not radioactive, and its concentration, therefore, does not vary in time. At present the $^{238}U/^{235}U$ ratio is 137.88 : 1.

The curves for a "concordant" distribution of daughter Pb isotopes start at a point with co-ordinates $^{206}Pb/^{204}Pb = 9.307$ and $^{207}Pb/^{204}Pb = 10.294$ (Figure 56a). These values are taken to represent the primordial Earth of 4.57 Ga. They are derived from the troilite phase of meteorites. The position of any curve on the plot in Figure 56a depends on the original concentration of uranium at larger concentrations; radiogenic lead accumulates more quickly, and the curve is steeper. The content of uranium is usually estimated with the aid of the parameter, m (= $^{238}U/^{204}Pb$), which takes into account the present-day concentration of uranium. The upper curve in Figure 56a is for m = 8.32. It is interesting that all curves for different m values should terminate on the same straight line, which happens to be the modern isochron (or geochron).

Straight lines which begin at the primordial point and pass to the left of the geochron, are called primary isochrons. In a reservoir with an unchanging (closed) U-Pb system, the isochrons correspond to the positions of points on the lead accumulation curves for different moments in the past.

Figure 56a

$^{207}Pb/^{204}Pb$

16

15

14

13

12

11

10

A

$^{206}Pb/^{204}Pb$

GEOCHRON

9   10   11   12   13   14   15   16   17   18
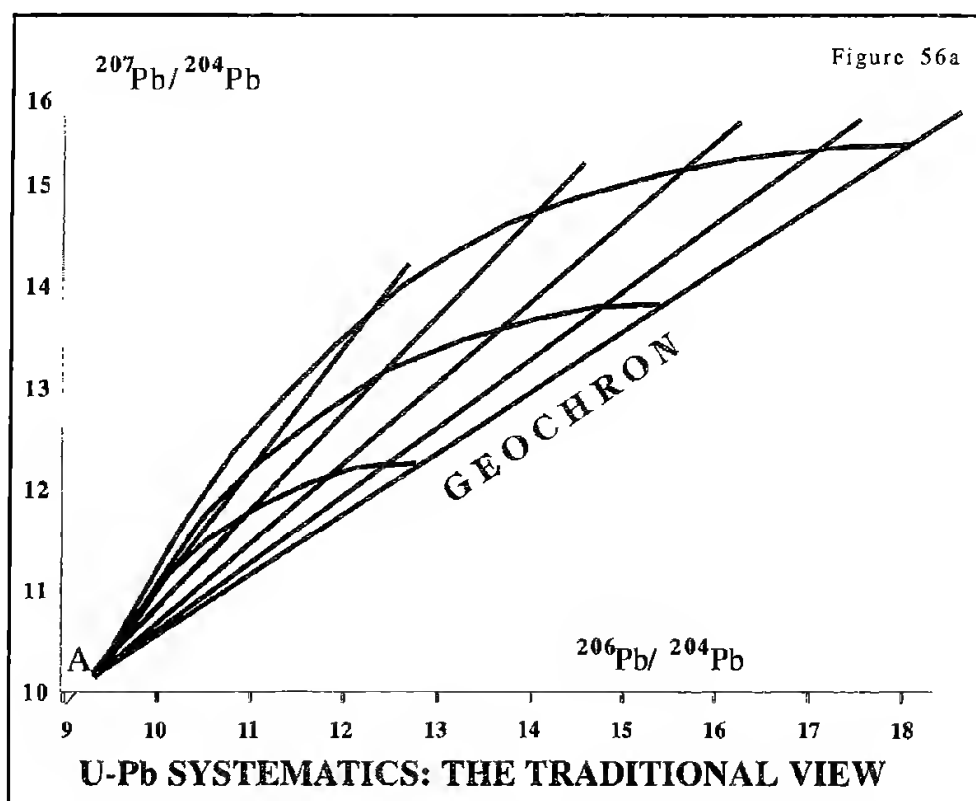
U-Pb SYSTEMATICS: THE TRADITIONAL VIEW

Figure 56a shows the evolutionary nature of lead isotopes from undisturbed uranium-lead systems. Point "A" represents initial (primordial) lead, which existed in the planetary body at birth. Its composition follows from that of the troilite phase of meteorites. Curves originating at point "A" show the evolution of the lead isotopes with time and according to the original U endowment.

With concordance to higher values of $^{238}U/^{204}Pb$ (m symbol) there is a growth of the "curve of concordant accumulation" of radioisotopes, ^{207}Pb and ^{206}Pb, from the decay of ^{235}U and ^{238}U. The straight lines originating from the initial point are called "initial isochrons." All undisturbed U-Pb systems must fall on these lines, which identify specific age dates.

The present isochron is called "geochron." The ends of the "curves of concordant accumulation" should all fall on this line, thus representing undisturbed decay systems, which have remained essentially closed to external isotope exchanges.

A straight line passing through a point on the concordant accumulation curve and the intersection point of the concordant accumulation curve with the geochron, is called a "secondary isochron," as illustrated for the secondary isochron passing through the point with an age of about Z Ga (Figure 56b). This configuration means that, if some sources with different U/Pb ratios had differentiated from the originally-homogenous mantle Z Ga ago, their modern $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ ratios should fall on this secondary isochron. The values in the uranium-depleted fraction move to the left of the geochron (dashed

line, CD), whereas the values for the uranium-enriched fraction shift to the right along the secondary isochron (dashed line CE).

U-Pb SYSTEMATICS: THE TRADITIONAL MODEL
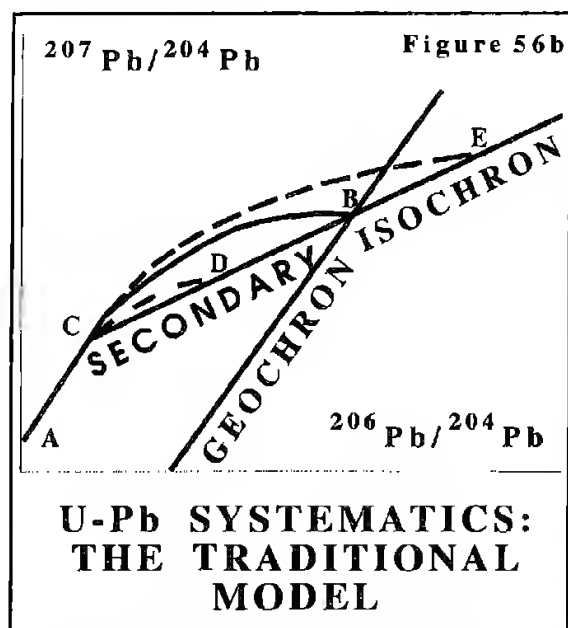
In Figure 56b curve AB is a line corresponding to "m_0." At time "C" the initial reservoir was divided into two sources, 1) an enriched source (with $m_1 > m_0$), and 2) a depleted one with ($m_2 < m_0$). Future evolution will fol-low the dashed curves. At present the two sources should both be on the straight line CDBE, which is known as the "secondary isochron." The depleted source should be located at point "D," and the enriched source at point "E." It is easily recognized that there is a simultaneous increase in the age of the event, which was initiated by the division of the initial reservoir, and the slope of the secondary isochron. Hence, the values from the right side of the isochron can be delivered only from an enriched source, in which the ratio, $^{238}U/^{204}Pb$, is a higher figure than that of the depleted and primordial sources located in the Earth's mantle.

A slope of a secondary isochron is determined by its initial point, i.e., by the time when the originally-homogenous reservoir was segregated into a number of fractions with different U/Pb ratios. And vice versa, the timing of segregation can be deduced from the slope of the secondary isochron.

Lead isotope data are presented for modern oceanic basalts, galena from the stratiform ores of various ages, and some other sources (Figure 57a). Pb isotope ratios in almost all oceanic basalts proved to fall to the right of the geochron, and within an area which can be reached only along a secondary isochron. On the basis of the slope of the entire trend, the age of this isochron should be about 1.5 to 2.0 Ga. One must, therefore, conclude that the mantle source of the basalts was differentiated 1.5 to 2.0 Ga ago, and another source had appeared with a U/Pb ratio higher than the initial average.

However, a depleted reservoir with a U/Pb ratio less than the initial value must have appeared simultaneously with the enriched reservoir. On the Pb-Pb diagram, magmatic rocks derived from the depleted reservoir had to fall to the left of the geochron. But the ratios indicative of the existence of the uranium-depleted reservoir are still unknown (in quantities compatible with the quantities of data to the right of the geochron). This phenomenon is called the "lead paradox."

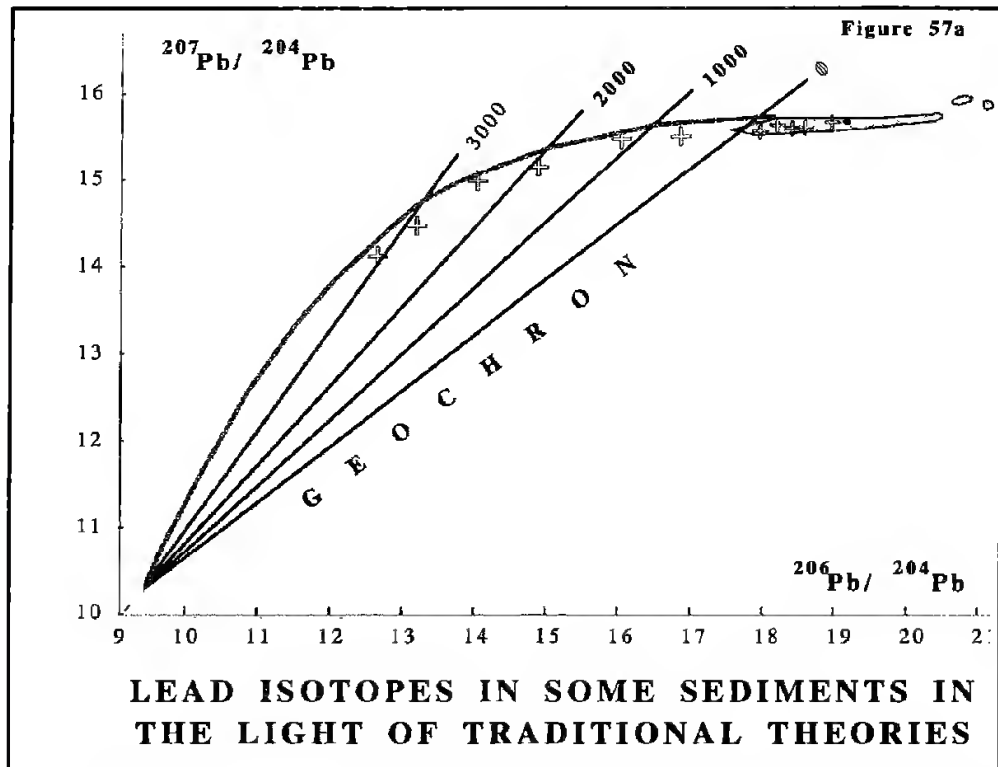**LEAD ISOTOPES IN SOME SEDIMENTS IN THE LIGHT OF TRADITIONAL THEORIES**

Figure 57a shows the lead isotope behavior in the light of traditional concepts. The grey area represents basalts from mid-ocean ridges ("MORBs") and oceanic islands. The crosses represent stratiform galena deposits. The shaded areas represent modern deep-water marine sedimentation. The curve representing concordant accumulation is drawn with m = 8.32. The oceanic basalt plotting, to the right of the geochron, implies that the basalt is, in fact, a derivative of enriched mantle (relative to U-Pb systematics). For an unknown reason, there is no derivative of depleted mantle in the sub-oceanic mantle, a phenomenon known in the literature as "the lead paradox."

Figure 57b shows some Earth features in the framework of the new Earth model. The initial point is shifted horizontally, because radiogenic ^{206}Pb is added in-situ from the decay of ^{234}U. The curves for concordant accumulation are drawn with m = 8 and m = 8.32. The dashed curve shows the concordant accumulation with m = 8.32 derived from the initial value in meteorites. The dotted line reflects the geochron position starting with the initial value in meteorites.

Figure 57b

LEAD ISOTOPES IN SOME SEDIMENTS IN
THE CONTEXT OF THE NEW THEORY
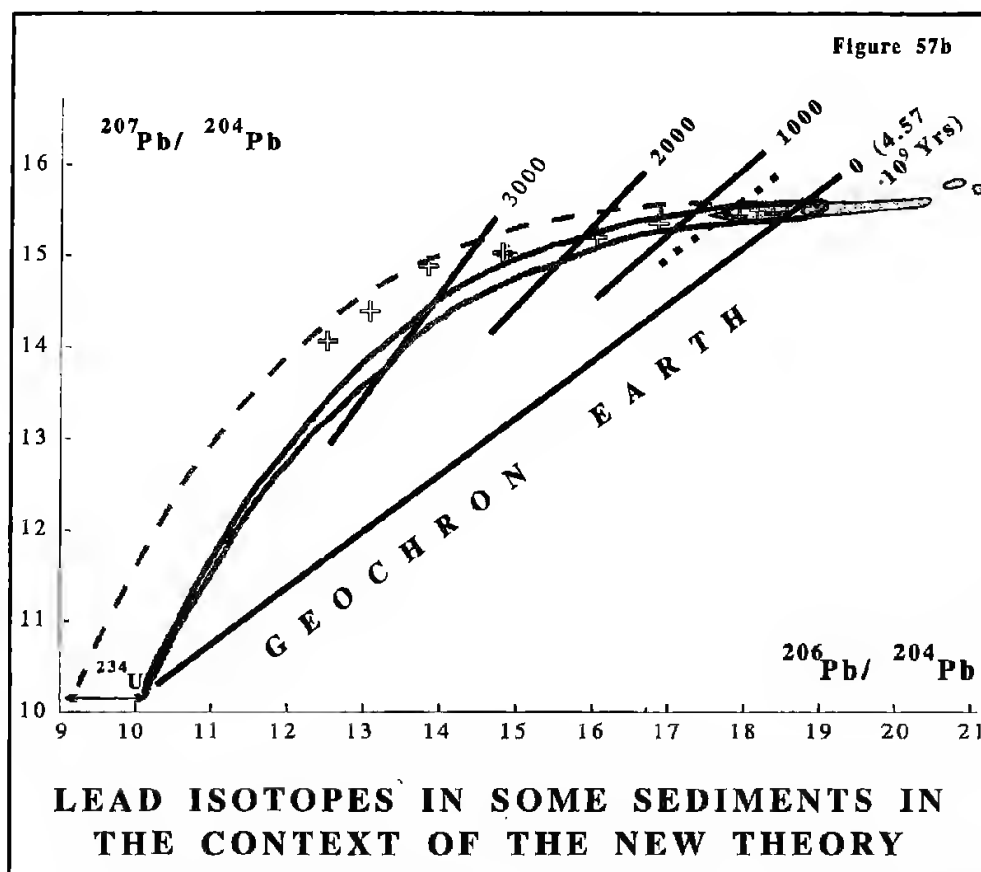
The location of galena (PbS) on the diagram can be explained as the presence of meteorite material that fell on the Earth's surface during the first 500 million years (see Chapter II). Because lead exhibits similar abundance in meteorites and on Earth (see Figure 2), there is no reason to discredit the idea of meteoritic lead imprinting itself in the oldest stratiform deposits. However, with the increase of mantle activity in crust-forming processes, the isotopic imprint of meteorites should gradually have been obliterated. This probably accounts for the gradual transition (some 2-3 Ga ago, when crustal development was most active) of galena from compositions intermediate between those of meteorites and Earth to those of Earth alone. Simultaneously, the m value for meteoritic material falling on the Earth's surface could very quickly equalize with the Earth's m due to the high mobility and lithophilic nature of uranium. This equilibration is emphasized by the fact that planetary volume is infinitely greater than meteorite pellets, which land on the Earth's surface.

Thus, the Rb-Sr, Sm-Nd, and U-Pb systemic data have been presented in a condensed form so as to outline the intrinsic paradoxes, which have been recognized in the process of data accumulation. Recently, many attempts have been undertaken among the oldest terrestrial formations to account for the lack of derivatives from a mantle reservoir enriched in terms of the Sm-Nd system, as well as for the absence of the depleted mantle source in terms of the U-Pb system

in recent basalts. The authors of these publications do not attempt a reformulation of the fundamentals of isotope geochemistry. Instead, they attempt solutions by formulating complex geodynamic systems that permit the existence of mantle reservoirs, as required by theory. Such reservoirs have never been discovered despite all the mass of available data. For these purposes, ideas like "subduction" or "mantle circulation" prove very useful. Inasmuch as the new model of the Earth dispenses with the need for these processes, we are moved to attempt to revise the fundamentals of isotope geochemistry.

So far, attention has been paid to the intra-systemic paradoxes in each isotope system, but inter-system paradoxes are of great interest as well. For instance, according to Rb/Sr and Sm/Nd data, oceanic basalts are derived from depleted mantle (Figure 55). On the other hand, the same basalts, if we judge from their U/Pb data (Figure 57a), are derived from an enriched mantle reservoir. The aforesaid isotope paradoxes, along with the discovery of significant cosmochemical regularity, take us to the very heart of the "fundamentals."

9.2 Resolving the isotope and cosmochemical paradoxes within the new model of the Earth: Revision of basic theory

The discovery of material cosmochemical regularities clearly favors the nebular origin of the Solar system, and, in turn, lets one speculate on the isotopic homogeneity of proto-matter in the nebula. As all isotopes of a single chemical element have similar ionization potentials, there would have been no isotope differentiation during magnetic separation. Therefore, the primary ratios of $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$, $^{206}Pb/^{204}Pb$, and $^{207}Pb/^{204}Pb$ during the formation of the Solar system had initially been identical everywhere, including the Earth and asteroid belt. The above statement correlates well with traditional views on the homogeneity of primordial isotope concentrations.

However, because of magnetic segregation, the initial relative concentrations of Rb/Sr, Sm/Nd, and U/Pb most probably differed between the respective zones of formation of the Earth and meteorites. These differences should increase as a direct function of differences in the ionization potentials of any such pair of elements.

The U-Pb system: a new approach

The positions of uranium and lead on the plot of element abundances versus ionization potentials (Figure 2) lead to the conclusion that the uranium concentrations on Earth must be higher by an order of magnitude than their counterparts in the asteroid belt. Primordial lead concentrations were similar on our planet and in meteorites.

It is worth noting that, apart from isotopes ^{235}U and ^{238}U, there is another isotope ^{234}U with a half-life of 2.44×10^5 years. Today this isotope is only encountered among the several radionuclides in the decay chain of long-lived ^{238}U. However, the relationship between element abundances in the cosmos and

their atomic masses, the "Oddo-Harkins rule," states that, during nuclear synthesis (the Supernova explosion responsible for the primordial distribution of elements in the Solar system), ^{234}U and ^{238}U were synthesized in similar quantities. This being the case, after several million years, the original ^{234}U would have decayed almost completely. The unanswered question is, how much time passed after nuclear synthesis and before magnetic separation isolated the proto-matter of the Earth within the proto-planetary nebula?

This question is of utmost importance, because both ^{234}U and ^{238}U decay to the same ^{206}Pb isotope. If this interval spanned not more than 1 to 1.25 Ma, ^{234}U could have been incorporated in noticeable amounts in the proto-matter of the Earth, whereas the quantity of this isotope in meteorites had to be less by an order of magnitude. Thus, the evolution of Pb isotopes on the Earth and in meteorites must have been markedly different during the first million years after magnetic separation. While the evolution in meteorites closely followed the concordant accumulation curve, a rapid horizontal shift to the right (rapid by comparison with the age of the Earth) had to occur in terrestrial matter, for the ^{206}Pb that had been accumulating from ^{234}U decay. Only after the ^{234}U supply had been exhausted, could lead evolution on Earth have followed the concordant accumulation curve.

Thus, the evolution curve of Pb isotopes on Earth should be shifted to the right with respect to the meteorite curve. The magnitude of the shift depends on its endowment of initially-captured ^{234}U, which, in turn, depends on the time span between the nuclear synthesis and magnetic separation.

This time span can be determined in different ways. It is instructive to consider the time interval required for collapse of a nebula of about one solar mass consisting of dust and gases, after its loss of gravitational stability and start of collapse into its center of gravity. Using Jeans' criterion which defines the temperature-density relationship in a gravitationally-stable interstellar cloud of diffuse matter, and also using the observed temperatures in such clouds, one can determine the following: a) the dimensions of the proto-solar nebula just before the start of the collapse; and b) the duration of the gravitational collapse to the proto-stellar state (a rapidly-rotating, dense nebula). These determinations are made when rotational instability in the proto-star has started and when, according to the new Earth model, magnetic separation is taking place.

Various solutions have been suggested by different authors (e.g., with or without a magnetic field). Common to all solutions is the conclusion that the duration of the collapse does not exceed 1 Ma. If this value is correct, then the share of ^{206}Pb attributable to the decay of ^{234}U on Earth is now about 11.5 percent of the share which is due to the decay of ^{238}U. This apportionment is conditional upon the two uranium isotopes having been synthesized in the same amounts during nucleo-synthesis.

If the shift of the initial point due to decay of short-lived ^{234}U is taken into account, the geochron of the Earth passes through the approximate middle of the distribution of data from oceanic basalts. It is absolutely clear that the new position

of the geochron destroys the lead paradox, since there are now two mutually complementary reservoirs, one depleted, one enriched (Figure 57b).

But is it necessary to draw the secondary geochron in order to account for the linearity of the oceanic basalt distribution and the continuation of this distribution beyond the geochron? In other words, does one have to assume that the mantle under the oceans had been differentiated into two reservoirs with low- and high-U/Pb ratios 1.5 to 2.0 Ga ago?

The lead accumulation curves that are drawn through the new starting point with m = 8.32 and m = 8.03 are compatible with oceanic basalts falling to the left of the geochron. This compatibility suggests an hypothesis that the observed pattern can be derived without mantle differentiation into two segregated reservoirs.

There are many minerals which concentrate uranium, among them apatite, sphene, zircon, and perovskite, which originally contained lead in negligible amounts, and hence, have U/Pb ratios of several hundreds or thousands for the non-radiogenic Pb isotope. Consequently, over time, the ratio of radiogenic Pb isotopes to non-radiogenic ones in these minerals will be much greater than for the whole rock. In addition, the atoms of the radiogenic Pb isotope in these minerals will be in "isomorphically hostile" settings. Thus, the rise of temperature and increasing fluid activity in magma generation will result in preferential escape of radiogenic lead into the melt, in contrast with non-radiogenic lead in "isomorphically friendly" settings in other principal minerals. Experiments have shown that acids or hot fluids of various composition are able preferentially to extract radiogenic Pb isotopes, enriching the fluids with radiogenic lead in comparison with the whole rock (both before and after the leaching).

Let us now assume that the $^{238}U/^{204}Pb$ ratios in the mantle range m' to m'' (Figure 58), and a U-concentrating phase had ceased at a moment A with respect to isotope exchange. At present, the evolution of Pb/Pb ratios in mantle matter has reached the geochron along the curves of the concordant accumulation with m' to m'', and the mantle partially melts at that moment. Simultaneously, the U-enriched phase may contribute its radiogenic lead to the partial melt. If the radiogenic Pb isotope accumulated in the solid matter since time A is totally transferred to the melt, and at the same time, if the non-radiogenic isotope (including ^{204}Pb) remains in the solid matter (both assumptions being extremely improbable), then the restite after partial melting will move back to point A on the Pb-Pb diagram, whereas the melt would shift to infinity along a ray drawn through the points A and P (Figure 58).

Of course, the aforesaid two assumptions can never happen, and the two extreme cases are given only as constraints. Judging from the foregoing arguments, one can state that Pb/Pb ratios in restite should fall within the AP interval, while the melt, in principle, may diverge far from the geochron, depending on the proportion of incorporated radiogenic and non-radiogenic isotopes.

Similar speculations can be repeated for different cutoff ages of the U-enriched

phase and slightly different values of m (for instance, line A'-P'-M', Figure 58). Finally, a new field will appear (shaded area, Figure 58), which does not significantly differ from the oceanic basalt field (Figure 57b). For outliers, like the Saint Helen, it is sufficient to assume a slightly longer existence of the U-enriched phase in the closed state (Figure 58, point E). Even in this case, the complementary restite values may remain in the field APA'P' provided that the melted phase is just a fraction of the restite volume.
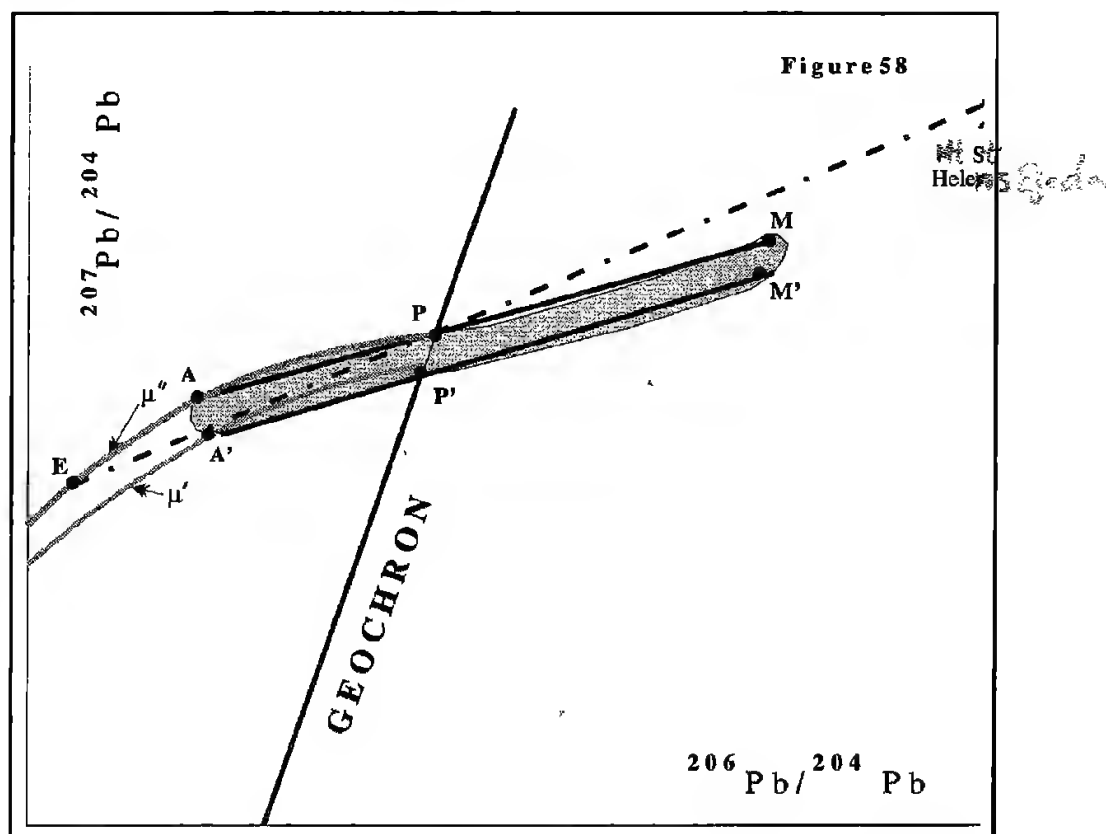
THE APPARENT SCHEMATICS OF THE U-Pb SYSTEM IN OCEANIC BASALTS IN LIGHT OF THE NEW THEORY
A detailed explanation will be found in the text.

Thus, the isotopic position of the oceanic basalt field is due to the evolution of the U/Pb system with time. The new interpretation contradicts the traditional view which assigns the inclination of the general trend to the heating and melting of the mantle, and to the division of the mantle into two reservoirs 1.5 to 2.0 Ga ago. Our interpretation attributes the slope of the general trend to the transition of the mantle into a cooler and, hence, less active state. Thiis is because deceleration of diffusion and the closure of mineral phases with respect to isotope exchange must be the result of temperature decline. Whereas the traditional approach requires a considerable increase in planetary geodynamic activity 1.5 to 2.0 Ga

ago, this increase in activity is no longer needed. Indeed, in the new model, closure of phases is an intermittent process over the time from a certain moment in the past up to the present (Figure 58).

The main conclusion is that the mantle produces the recent oceanic basalts, which in accordance with the new model, have evolved in a single-stage process to the present day, reaching the geochron along the concordant accumulation curve. Therefore, the mantle under the oceans is the original undifferentiated mantle where the U-Pb system had always been closed with respect to isotope exchange, and, therefore, has never participated in active magma-producing processes.

This outcome is in diametric opposition to plate tectonics, but in good agreement with the new model of the Earth and with the observable nature of planetary geodynamics. It is worth reminding ourselves that, according to the new model, undifferentiated matter arrives at depth, beneath the central parts of the oceans, from the core. In the core, this matter is most unlikely ever to have been differentiated, because, since the collapse of the proto-planet, it was preserved as hydrogen compounds (hydrides) until quite recently in geological terms.

Therefore, on the basis of U-Pb systematics in a context of the new model of the Earth, oceanic basalts, including MORB, can be produced by original, undifferentiated mantle. However, this conclusion, as well as the traditional version, fails to corroborate the implications of Sm-Nd and Rb-Sr systematics; and it is necessary to reconsider these systematics in the light of the new cosmochemistry.

Sm-Nd systematics: a new approach

Primordial Sm/Nd and $^{143}Nd/^{144}Nd$ ratios on Earth are traditionally equated with their counterparts in meteorites. This view, however, requires re-evaluation because of the dependence between elemental abundances and ionization potentials that we have established. Initial $^{143}Nd/^{144}Nd$ ratios were certainly the same for the entire Solar system, but the initial Sm-Nd ratio should vary with distance from the Sun, because the ionization potentials of Sm and Nd are 5.6 and 6.3 volts, respectively.

Because the potential is lower for samarium than for neodymium, the initial Sm/Nd ratio after magnetic separation should be higher on Earth than in meteorites. But it is difficult to evaluate how much higher it may have been, because it is not known whether the initial Meteorite/Earth trend was uniformly linear or broken (gentler-to-steeper slopes representing lower-to-higher ionization potentials; Figure 59). The experimental data shown in Figure 2 do not permit any definite conclusion on this point. Nevertheless, the very existence of the trend implies that initial Sm/Nd ratios could not have been the same on Earth as in meteorites. Those ratios in the Earth most probably were higher.

We should now reconsider the mantle array, that is to say, the negative correlation between the $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ in mantle-derived objects

(Figure 55). Most remarkable is the fact that there is a definite correlation between the mantle array and the depth of magma generation, the latter growing regularly from MORB to alkali basalts of the Kerguelen Island type. This correlation has led to the hypothesis that the mantle array is caused by selective melting of clinopyroxene, while garnet remains in the restite. It is worth noting that the clinopyroxenes from mantle nodules fall precisely on the trend of the array and its continuation. Other principal mantle minerals like olivine and orthopyroxene, can be excluded from consideration, because they are depleted in rare- earth elements.
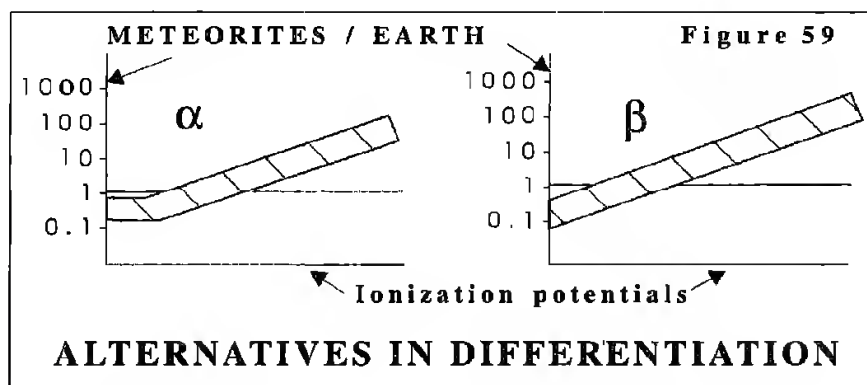

Figure 59 shows two variant interpretations of the empirical data (see Figure 2) The curved trend in a assumes that in the primordial plasma the elements with lower ionization potentials must have been totally and uniformly ionized, whereas elements with higher ionization potentials should be less affected by the plasma background

The idea that garnets are preserved in restite during mantle melting is now confirmed by numerous data on the REE distribution in mantle-derived rocks (Figure 60) and also by numerous experiments, which have demonstrated that, during melting under high pressures, garnet is the last phase left in the melt (Figure 61).

According to the REE distribution in minerals from mantle nodules (Figure 62), Sm/Nd ratios in garnet are 2.5 to 3.0 times above those in clinopyroxene. Let us assume the ratio is only 2.0 and consider the consequential evolution of the $^{143}Nd/^{144}Nd$ ratio in these two minerals in the mantle (under conditions of a closed system relative to them). Variations for their fractionation and durations of exposure are shown in Table 13.

Numerical simulations show that the 1.5 to 2.0 Ga exposure is sufficient in closed mineral systems for negative ε_{Nd} values similar to those observed in present-day mantle nodules to accumulate in clinopyroxenes (Figure 55). Therefore, selective melting of clinopyroxene with garnet remaining in restite can lead to the ε_{Nd} values exhibited by the mantle array.

Figure 60

RARE-EARTH ELEMENT
DISTRIBUTION IN ROCKS
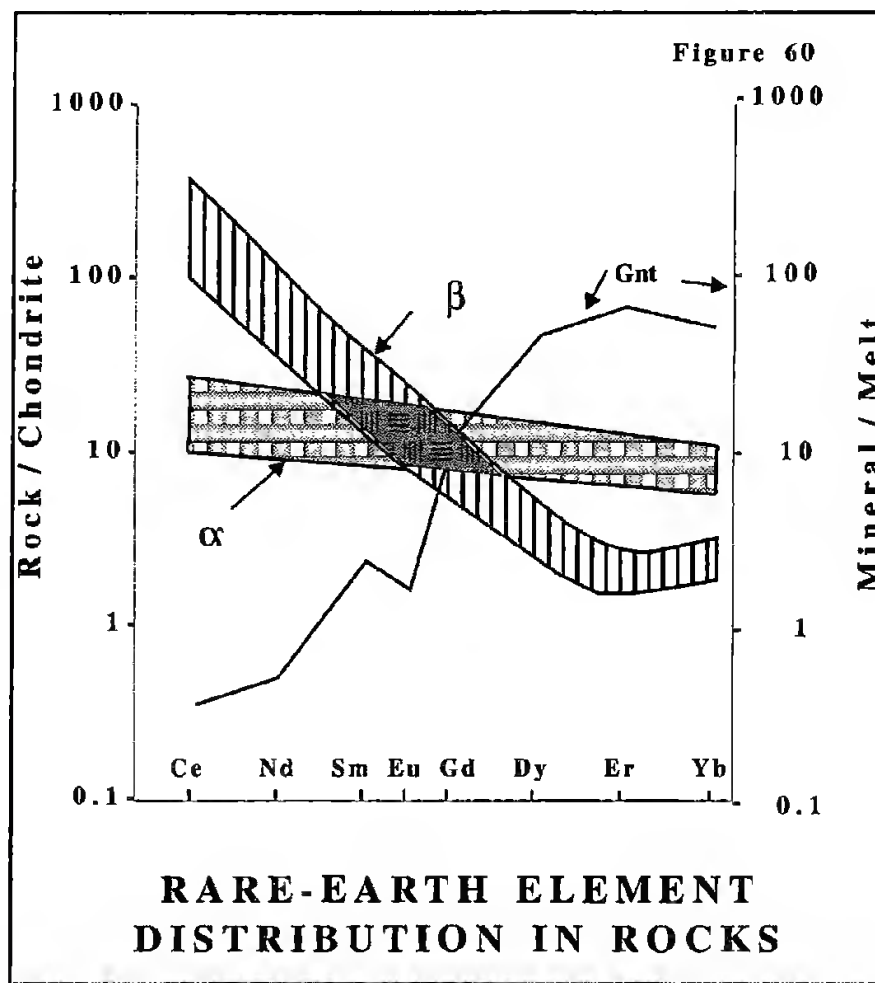
In Figure 60 a depicts the deepest mantle eclogites; b depicts kimberlites (generalized data after Dowson 1983). The broken line depicts the coefficient of fractionation of rare-earth elements in garnets ("Gnt") (Hanson 1980)

However, if one adopts the selective melting of clinopyroxene in the primary mantle, where it is not diferentiated into reservoirs, in order to explain the ε_{Nd} variability in mantle-derived magmatic rocks, the method of evaluation of the ε_{Nd} value in modern mantle must be performed in an entirely different way. From the author's point of view, the average value for the entire range of ε_{Nd} values observed in mantle-derived rocks is meaningless. Realistically, if the "garnet-pyroxene couple" prevails, the ratio of $^{143}Nd/^{144}Nd$ in the melt can only decrease steadily with respect to its initial value in the mantle matter.

Therefore, the average $^{143}Nd/^{144}Nd$ ratio of the modern mantle should lie among high ε_{Nd} values for mantle-derived magmatic rocks. At the same time, this average ratio cannot be a maximum, since ε_{Nd} values in mantle matter tends to increase as melting proceeds, and the melt selectively consumes a component with $^{143}Nd/^{144}Nd$ ratio less than the initial ratio. Thus, the subsequent melts

from already partly-depleted mantle should have higher $^{143}Nd/^{144}Nd$ ratios in comparison with the preceding melts.

One should determine which part of the high $\mathcal{E}_{Nd}$ values in basalts is related to the depleted mantle. It is likely that the volume of melted mantle matter exceeds, at least by a factor of ten, the volumes of produced basalts. Thus, the growth of $\mathcal{E}_{Nd}$ in depleted mantle should be about one-tenth the observed range of $^{143}Nd/^{144}Nd$ ratios in basalts. As a first approximation, this reasoning implies that the undepleted mantle at present should have $^{143}Nd/^{144}Nd$ ratios about $\mathcal{E}_{Nd} = +8.5$ to $+9.5$.

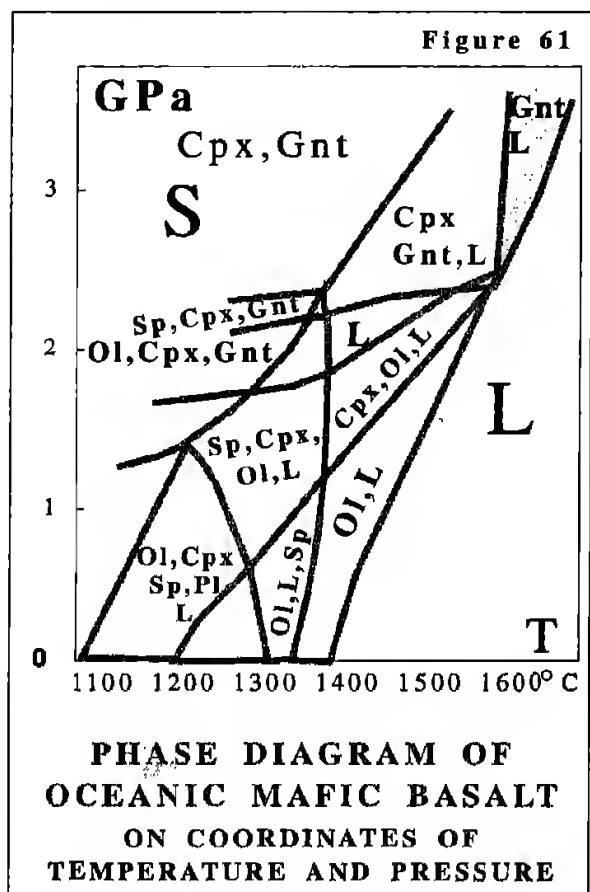Figure 61

GPa

Cpx,Gnt

S

L

Figure 61 is a phase diagram of mafic oceanic basalt on coordinates of pressure and temperature. The shaded area is the field of garnet stability (as the single phase) of the liquidus.

Pl = plagioclase,
Ol = olivine,
Cpx = clinopyroxene,
Sp = spinel,
Gnt = garnet,
L = liquid phase,
S = solid phase
(after Maalfe & Jakobsson, 1980).

PHASE DIAGRAM OF OCEANIC MAFIC BASALT ON COORDINATES OF TEMPERATURE AND PRESSURE

However, the undeplet-ed mantle can reach this level only if Sm/Nd ratios on Earth were originally higher than in meteorites, the likely result of magnetic separation. If $\mathcal{E}_{Nd} = +9$ is the mean for the modern undifferentiated mantle, then the original $^{147}Sm/^{144}Nd$ ratio on Earth is 0.2179, or 7.5 percent above the CHUR figure. For this original $^{147}Sm/^{144}Nd$ ratio, the $\mathcal{E}_{Nd}$ value in the mantle 3.8 Ga ago should have been +1.52. It means that the rocks 3.7 to 3.8 Ga old, which yield, on average, precisely these positive $\mathcal{E}_{Nd}$ values, are the carriers of the Nd/Nd label of undifferentiated, original mantle, not depleted mantle as the traditional point of view requires. It is apparent that there is no need to look for an enriched reservoir, and the paradox of Sm/Nd systematics disappears. It is perfectly clear that this paradox results from the unquestioned acceptance of the identity between Sm/Nd ratios of meteorites and the primordial Earth.

TABLE 13
$\mathcal{E}_{Nd}$ IN COEXISTING CLINOPYROXENE (Cpyx) AND GARNET (Gnt)

PHASE $\Sigma = 100\%$ Gnt / Cpyx	DURATION OF MINERAL PHASES IN THE CLOSED STATE (YEARS)			
	0.0	1.0×10^9	1.5×10^9	2.0×10^9
1 / 99	0 / 0	+25.7 / - 0.3	+38.5 / - 0.4	+51.4 / - 0.6
10 / 90	0 / 0	+21.4 / - 2.4	+32.2 / - 3.6	+42.9 / - 4.8
20 / 80	0 / 0	+17.5 / - 4.4	+26.2 / - 6.6	+34.9 / - 8.8
50 / 50	0 / 0	+ 8.7 / - 8.7	+13.1 / -13.1	+17.5 / -17.5
75 / 25	0 / 0	+ 3.7 / -11.0	+ 5.2 / -16.7	+ 7.4 / -22.5

Commentary: *The initial $^{147}Sm/^{144}Sm$ and $^{143}Nd/^{144}Nd$ ratios in the garnet-clinopyroxene mixture coincide with the CHUR which is also used as the standard. Calculations are performed under a condition that Sm/Nd ratio in garnet is twice that in clinopyroxene for any Cpyx/Gnt mixture.*
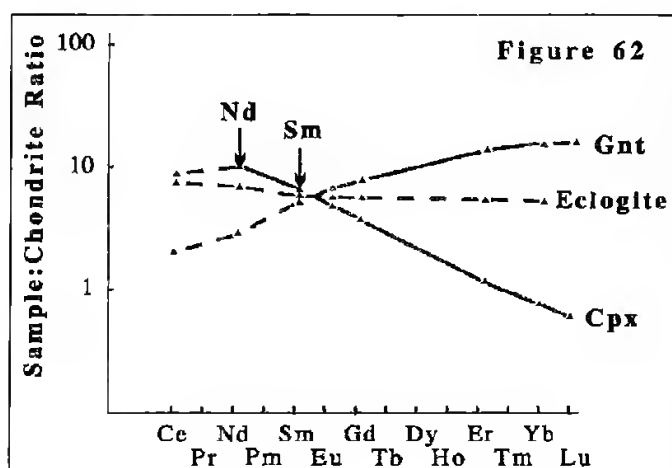
Figure 62 shows the distribution of rare earth elements in eclogite and its various rock manifes-tations in the Robert Victor pipe. Gnt = gar-net, Cpx = clinopyroxene (from Dowson, 1983).

The new model of Nd/Nd evolution on Earth (Figure 54b) should be treated as one of a range of possible scenarios based on the assumption that the original Sm/Nd ratio on Earth could have been and must, in fact, have been higher than in meteorites because of magnetic

differentiation in the proto-planetary disk. The new model (Figure 54b), which precludes negative or zero ε_{Nd} values in rocks with the ages of 3.8 to 3.0 Ga, is preferable to the traditional model (Figure 54a), wherein such values are permissible.

The results of calculation of ε_{Nd} values in co-existing clinopyroxene and garnet in the mantle, which were obtained during the evaluation of the original $^{143}Nd/^{144}Nd$ ratio of 0.2179, are most interesting.

For a certain proportion of phases, e.g., 50/50, it proved to be possible to obtain the entire ε_{Nd} range in natural mantle clinopyroxenes, from +6.5 to -15, not only by increasing the depth (which corresponds to increase of the garnet content), but also by increasing the duration of exposure in the closed state from several hundred Ma to 2.5 Ga.

TABLE 14

ε_{Nd} VALUES IN COEXISTING CLINOPYROXENE (Cpyx) AND GARNET (Gnt) IN VARIOUS PROPORTIONS AND VARIOUS DURATION OF EXPOSURE IN THE CLOSED STATE

PHASE $\Sigma = 100\%$	DURATION OF EXPOSURE OF MINERAL PHASES IN THE CLOSED STATE (Ga)					
Gnt / Cpyx	0.0	0.25×10^9	1.0×10^9	1.5×10^9	2.0×10^9	2.5×10^9
1 / 99	+9 +9				+61.1 +6.6	+75.0 +6.4
5 / 95	+9 +9	+14.8 +8.3			+57.0 +4.5	+60.7 +3.8
10 / 90	+9 +9	+14.2 +8.0	+30.0 +5.3		+52.2 +2.1	+63.7 +0.8
20 / 80	+9 +9		+25.9 +3.2	+34.8 +0.5	+43.8 -2.1	+53.3 -4.4
33.3 / 66.6	+9 +9			+27.9 -2.9	+34.7 -6.7	+41.7 -10.2
50 / 50	+9 +9	+10.9 +6.4	+16.8 -1.4	+21.1 -6.4	+25.5 -11.2	+30.2 -15.9
75 / 25	+9 +9					+17.0 -22.9

Commentary on Table 14:. *The original $^{147}Sm/^{144}Nd$ ratio in the mantle is 0.2179, which corresponds to $E_{Nd} = +9$ (the mantle average today). The CHUR is taken as the standard. Calculations are performed under the condition that the Sm/Nd ratio in garnet are twice those in clinopyroxene for all Gnt/Cpyx ratios.*

It is likely that both the duration of exposure and depth are at work. Which prevails in a given case can be deduced from ε_{Nd} values in co-existing garnets. If the depth is the main factor, ε_{Nd} values should not drop below +30 and range +30

to +75. By contrast, if time is the main factor, these values should range from +10 to +30, but not higher. If both mechanisms are responsible, as illustrated by diagonals (Table 14), mantle garnets should reveal a narrower ε_{Nd} range, from +25 to +35.

When more data are available in future, the resolution may become clearer. However, even today, there are indications that durations of exposure are extremely important, because ε_{Nd} values in garnets are usually below +30. In this connection, one can assume that mantle-derived rocks (in the left, upper part of the trend diagram; Figure 55) were produced by shallow, young mantle, whereas the right, lower part of the mantle array was produced from deeper, older, mantle matter.

Thus, the new approach to Sm-Nd systematics, as well as to U-Pb systematics, leads to the conclusion that oceanic magmatic rocks can be produced by original, undifferentiated mantle.

The Rb-Sr system: a new approach

To this point we have analyzed isotopic data from the oceans mainly in order to exclude possible contamination of mantle-derived magmatic rocks with sialic matter from ancient continental crust. For Rb-Sr systematics, the crust and mantle of the continents should be considered first.

It has already been mentioned that there is no break in the evolution line for strontium ratios in the terrestrial mantle, according to the traditional view (Figure 53a). However, because of the intense lithophilic affinities of rubidium and, hence, its inevitable depletion in the mantle during crust formation, a break must be present on its evolution line. Moreover, to understand Rb-Sr systematics properly, it is very important to determine the precise position of this break in the evolution line of the mantle $^{87}Sr/^{86}Sr$ ratio.

The link between element abundances and ionization potentials (Figure 2) unquestionably implies that rubidium concentration on Earth should exceed that in meteorites manyfold. Therefore, based only on rubidium concentrations, there should exist two reservoirs under the continents. The same situation was shown to be necessary for potassium (Chapter VII. 1), where the depleted and primary (undepleted) reservoirs define restite and hypolite, respectively.

The relationship between elements and ionization potentials precludes precise determination of the Earth's initial rubidium and strontium concentrations. Nevertheless, it is possible to state that evolution of the $^{87}Sr/^{86}Sr$ ratio in hypolite started 4.57 Ga ago, simultaneously with its start in meteorites, "BABI" = 0.699. Once the crust had appeared, approximately 2.5 Ga ago, and the evolution line of restite branched off from the primary reservoir; its evolution line should be less steep than the evolution line for hypolite.

Mantle dunite-harzburgite nodules, which are common in continental basalts, can most probably be considered samplings of mantle restite. In these nodules, the mean $^{87}Sr/^{86}Sr$ ratio for 18 samples has been reported as 0.70693 (Powell, 1974), and their Rb/Sr ratio as 0.02 (Stueber & Murthy, 1966). Using these

values and equations (7) and (10), one can determine that the $^{87}Sr/^{86}Sr$ ratio in restite was 0.70489 at 2.5 Ga (when the continental crust had been formed). This initial ratio for restite should also fall on the hypolite evolution line.

Thus, two points for hypolite are established: "BABI" $^{87}Sr/^{86}Sr = 0.699$ with the age of 4.57 Ga; and $^{87}Sr/^{86}Sr = 0.70489$ with the age of 2.5 Ga. The straight line drawn through these two points corresponds to the evolution line of Sr isotopes in hypolite. At present, this line yields $^{87}Sr/^{86}Sr = 0.712$ and Rb/Sr = 0.07 in this reservoir (Figure 53b).

According to the new model, undepleted mantle with the present-day $^{87}Sr/^{86}Sr$ ratio 0.712 should now be emerging in the oceans. However, such values are unknown. In order to account for this anomaly, it is necessary to analyze the data for basalts from mid-oceanic ridges and oceanic islands (Figure 63). The geochron with the age of 4.57 Ga has been added to the drawing. Reservoirs with various initial Rb/Sr ratios, which have lost neither rubidium nor strontium since 4.57 Ga (hypolite, for example) should fall on this geochron. The geochron with the age of 2.5 Ga linking restite, hypolite, and continental crust is also shown in this figure. Obviously, these reservoirs correspond to the continents and underlying mantle.

Data on basalts are scattered (Figure 63), thus implying severe distortions of the Rb/Sr system in the basalt-producing mantle. In this chaotic situation, one may recognize distinct isochrons with ages not exceeding 1.25 Ga. One may discern at the same time that most data on basalts tend to disperse horizontally, thus implying that the distortions of the Rb/Sr system took place in the most recent stage of planetary evolution.

The scatter of the points both to the left and right of the geochron shows that the distortion of the Rb-Sr system was simultaneous with the loss of both rubidium and radiogenic strontium. In the framework of the new model of the Earth and its geodynamics, one has to link this loss to the formation of the modern oceans and to contemplate loss by the underlying mantle, during the formation and growth of the oceans, of huge amounts of rubidium and radiogenic strontium from original concentrations in the hypolite (i.e., by comparison with the average on Earth).

Thus, the Rb/Sr system points to the following evolution: (1) The undepleted mantle breaches the crust, "spreading" the ocean basin. (2) Rubidium and radiogenic strontium are lost during this breaching. (3) Only afterward does the mantle start to produce basalts. Farther on in this book, this evolution will be considered repeatedly to demonstrate that, within the framework of the new model of the Earth, the loss of lithophilic elements preceding basalt production is not mysterious. One can reasonably maintain that, as the loss of rubidium and radiogenic strontium has occurred in recent history and not far in the past, the basalt data do not allow any deduction as to whether the mantle under the oceans is depleted or primordial.
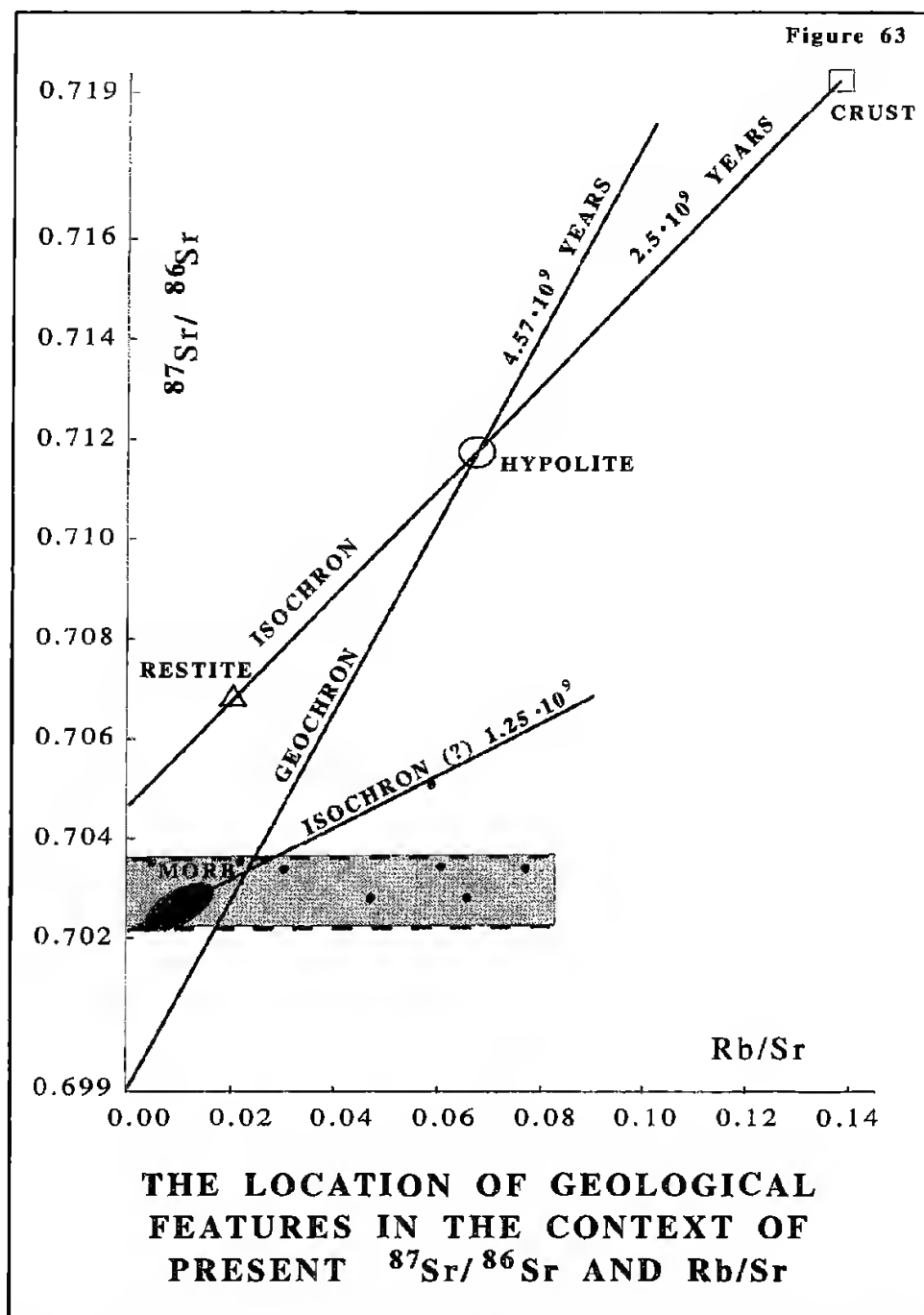
Figure 63

THE LOCATION OF GEOLOGICAL
FEATURES IN THE CONTEXT OF
PRESENT $^{87}Sr/^{86}Sr$ AND Rb/Sr

*Figure 63 is a plot of present ratios of $^{87}Sr/^{86}Sr$ and Rb/Sr in some constituents of the
Earth. Systems that have remained undisturbed throughout Earth history must fall on
the "Geochron." For example, the primordial "gypolite," connects the complementary
reservoirs, "crust" and "restite" through the isochron $2.5 \cdot 10^9$. The dark grey area is
Mid-Ocean Ridge Basalt ("MORB"); dots in the light grey area represent oceanic island
basalts. The horizontal trend of the oceanic basalts represents acute distortion of the
Rb-Sr system in the mantle below the oceans during the present stage of planetary
development. As a minimal statement, we can assert that basalts falling below the*

geochron are depleted in radiogenic strontium, and those falling above it are depleted in rubidium. Simultaneous catastrophic losses of rubidium and radiogenic strontium from the mantle source of modern oceanic basalts are still a possibility.

It is appropriate now to return to the problem of the negative correlation between $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ (Figure 55). This correlation exists in spite of the fact that the Rb/Sr system in the mantle under oceans has clearly been distorted in a most radical manner, while the Nd/Sm system has remained closed.

The entire range of ε_{Nd} values in clinopyroxenes is most probably due to variations of the lengths of exposures of their mineral phases in the closed state on the one hand, and variation of depth, on the other (Table 14 and its discussion). The same mechanisms appear to determine the regular growth of $^{87}Sr/^{86}Sr$ ratios in mantle-derived rocks. Within the framework of the new model of the Earth, basalts of mid-oceanic ridges, MORB, are produced by the young shallow mantle (Figure 55), which in turn is produced in the axial parts of the oceans at limited depths by transformation of intermetallic silicides into silicate minerals. Low $^{87}Sr/^{86}Sr$ ratios in these basalts are most probably due to the loss of radiogenic strontium during the transformation.

According to experimental data (Shimizu, 1971) and observations on natural objects (Sobolev et al., 1971), the proportion of jadeite component ($NaAlSi_2O_6$) in clinopyroxenes increases with elevated pressures. This component can carry potassium and rubidium isomorphically; for instance, a 0.27% concentration of K_2O has been found in omphacites in diamonds. The higher the pressure under which clinopyroxene is formed and preserved, the larger the rubidium component in its lattice.

Clinopyroxenes from mantle nodules in kimberlite pipes most probably represent the deep mantle of ancient cratons. Calculations (Table 15) made on rubidium concentrations actually found in abyssal clinopyroxenes show that they can account for the entire range of $^{87}Sr/^{86}Sr$ ratios in this mineral phase (see clinopyroxenes, Figure 55) provided that clinopyroxenes were preserved in a closed system for 2 to 2.7 Ga (implying an abyssal and ancient mantle).

Thus, within the framework of the new model of the Earth, one can state that the young shallow mantle should have high $^{147}Nd/^{144}Nd$ and low $^{87}Sr/^{86}Sr$ ratios, whereas the ancient abyssal mantle should have low ε_{Nd} values and high $^{87}Sr/^{86}Sr$ ratios. This fully explains the mantle array (Figure 55). The upper left and lower right parts of the array are produced by the young shallow mantle and ancient abyssal mantle, respectively.

TABLE 15
CALCULATED ^{87}Sr / ^{86}Sr RATIOS IN CLINOPYROXENE FOR RECORDED CONTENTS OF RUBIDIUM AND STRONTIUM

CONCENTRATION [Grams/Tonne]		DURATION OF EXPOSURE OF CLINOPYROXENE IN THE CLOSED STATE [Ga]			
Rb	Sr	2.0×10^9	2.0×10^9	2.5×10^9	2.7×10^9
0.51	177	0.7055	0.7065	0.7052	0.7046
3.4	177	0.7068	0.7078	0.7068	0.7064
9.0	177	0.7093	0.7103	0.7100	0.7098
RESERVOIR		RESTITE	HYPOLITE		

Commentary: *Strontium content of 177 grams per ton is obtained from an average of seven samples of mantle clinopyroxenes (Dowson, 1983). Rubidium contents of 0.51 and 3.4 grams per ton are minimal and maximal values for 11 analyses (ibid.). Rubidium content of 9.0 grams per ton is calculated for K_2O content of 0.27% and K/Rb ratio of 250. It is assumed that the initial $^{87}Sr/^{86}Sr$ ratio in a mineral for the moment of the closure of the system is equal to the average in the corresponding reservoir at the same moment of time (see Figure 53b).*

It is evident that assimilation of the ancient sialic substratum with high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ ratios by mantle magma may play an important role in formation of the mantle array (Figures 53b and 54b). Nevertheless, a presumption of widespread assimilation of ancient crust by mantle magma is unreasonable in many places, because there is no evidence of any interaction of the magma with crustal xenoliths, which commonly are found retaining their acute-angular forms unaltered at their contacts (Luts, 1974).

Furthermore, mantle magmas often have an increased content of strontium and rare earth elements. From this background data, any bias of $^{143}Nd/^{144}Nd$ and $^{87}Sr/^{86}Sr$ ratios from assimilation of ancient crust would have required such a magnitude of consumption of sialic material that it would have greatly affected the petrochemistry of the mantle-derived magmatic rocks. However, petrochemical data on these mantle-derived rocks usually reveal no significant contamination.

Finally, the fact that natural clinopyroxenes from abyssal nodules fall within the mantle array and its continuation (Figure 55) strongly supports the validity of our approach to this problem, inasmuch as clinopyroxenes from mantle xenoliths could not have assimilated sialic substances.

Commentary on the foregoing themes

The oxygen-deficient, intermetallic mantle approaching the planet surface in rift zones, most probably can never be exposed because its components react with the hydrosphere, where it is oxidized and hydrogen gas released. The intermetallic mantle has high thermal conductivity, which makes its local melting unlikely. Therefore, no possibility exists for finding melts from this zone. However, although the intermetallic mantle can not be discovered in nature, it may still be possible to reach it by deep boreholes in particular structural settings.

Experimental data show that, with pressure increase, the isomorphic capacities of the lattices of mantle minerals (garnets and pyroxenes) also increase. This is the case for lithophilic elements in particular. Moreover, new mineral phases, which are able to concentrate rare and trace elements may appear under conditions of increased pressure. For instance, the replacement of Ca and Si by Na and P was found in garnets under pressures above 1.8 GPa. The solubility of Na and P in garnets grows steadily up to pressures of 4.5 GPa (Thompson, 1975).

According to the new model, the entire silicate-oxide shell of the Earth resulted from transformation of intermetallic silicides. However, in the past, this process had predominantly taken place under higher pressure, and not only because of greater depth. The new model assumes a considerable increase of planetary volume and hence much stronger gravity in the past, that is to say, the vertical gravity gradient was higher in earlier stages of planetary evolution. Therefore, mantle transformation in the past was not accompanied by so severe a loss of lithophile elements, including rubidium and radiogenic strontium, as today during the formation of MORBs under mid-oceanic ridges. In other words, the mantle MORB source may not have existed in the past (perhaps, in pre-Mesozoic time).

The implication is that tholeiitic paleobasalts can not be an exact counterpart of modern MORB. This has already been demonstrated by the exhaustive analyses of Luts (1980). It also implies that the formation of the MORB reservoir in the mantle is accompanied by large-scale expulsion of various lithophilic elements, which in turn are buried in oceanic sediments. The scale of this entire expulsion/burial process must have proceeded on a much smaller scale in the past.

It would be very interesting to discover the sources of several elements, which occur as enrichments in oceanic sediments, particularly K, Rb, TR, Hf, Th, Zr, and U. Perhaps it then could be shown that these enrichments in deep-sea sediments are from the same mantle sources as depleted basalts. The data on the Rb-Sr system, as well as the maps of element distribution in oceanic sediments, do suggest this possibility. The pattern should be clearest for elements which combine as relatively insoluble compounds and, thus, cannot be redistributed widely. For instance, the concentration anomalies of lanthanum, hafnium, zirconium, and yttrium clearly point to their source within mid-oceanic ridges (Figure 64). Thus, there is reliable evidence that lithophilic elements are actually being extracted and transferred, but the scale of process remains unknown.

For concluding remarks, it should be stressed that, within the relationship between element abundances and ionization potentials, the primordial U/Pb, Rb/ Sr, and Sm/Nd ratios should differ on Earth and in meteorites. When this relationship is taken into account, all paradoxes in the discussed isotope systems disappear.

One can say without hesitation that, during ocean formation, undepleted mantle emerges in the axial zones of the modern oceans. This conclusion is in perfect agreement with geodynamics as deduced from the new model of the Earth (Chapter VIII, 2, Figures 46, 47), and in direct contradiction to plate tectonics, in its aspect of mantle convection in particular. This latter mechanism presumes that each volume of mantle repetitiously participates in magma generation, as it circulates under the oceanic structures.

In our approach to problems of isotope geochemistry, the number of mantle sources is reduced to three. Under continents, those sources are hypolite (the original mantle), which has been preserved since the initial stage of Earth evolution, and restite (the depleted mantle) which was formed from hypolite as the result of the escape of lithophilic elements into the continental crust. In the axial parts of spreading zones, another MORB-producing reservoir is added. This reservoir is the product of the transformation of extremely primitive (original and undepleted) intermetallic substance of the planet into silicate-oxide mineral.

A few words are in order here on the "stability and mobility" of isotope systems: The parent and daughter isotopes of the Sm-Nd system are similar in their properties (ion radius, valences, chemical affinities). Their geochemical characteristics are also similar. That is why radiogenic ^{143}Nd does not usually migrate far from its "birth-place", but remains in "isomorphically-hospitable" samaruim-bearing mineral.

The situation is drastically different for the Rb-Sr system where parent and daughter isotopes differ by ion radius, valences, and chemical affinity. That is why the daughter ^{87}Sr is "out of place," and its atoms take any opportunity to diffuse and migrate from its native, rubidium-bearing source mineral. It is not surprising that the preferential migration of radiogenic strontium is common while non-radiogenic atoms of this element are firmly attached to the lattices of calcium-bearing phases by the strong isomorphism of calcium and strontium.

Many examples are available to illustrate the preferential migration of radiogenic strontium and the resulting distortion of $^{87}Sr/^{86}Sr$ ratios have been published. It is sufficient to refer to lamproites where $^{87}Sr/^{87}Sr$ ratios vary from 0.702 to 0.722. Values larger than the mean of ancient sialic matter (0.719) cannot be attributed to assimilation of continental crust. On the other hand, ε_{Nd} values in lamproites do not vary, and thus illustrate the inertness of one system and the mobility of the other.

The U-Pb system is of special importance as there are two parent and two daughter isotopes. Uranium and lead are quite easily separated by geochemical processes, but no natural process is able to separate ^{235}U and ^{238}U. At the same time, the differences in decay constants of these two isotopes and the tendency of daughter isotopes to migrate from the native U-bearing phase, provide opportunity for study of the evolution of the U-

Pb system. In general, the simultaneous analysis of mobilities in several isotope systems is worthwhile, because one may find an opportunity to date different events.
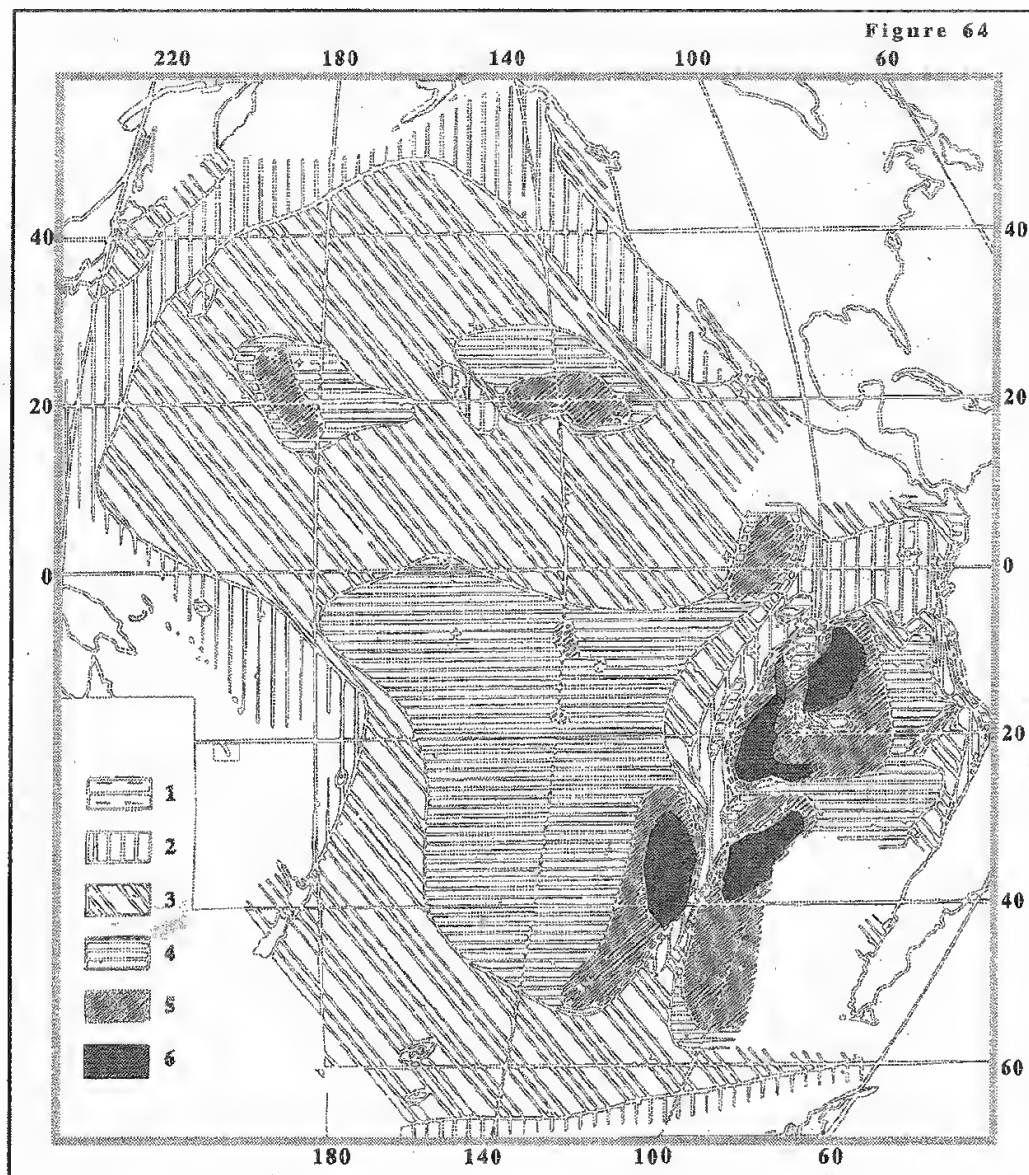
Figure 64

HAFNIUM IN SEAFLOOR SEDIMENT OF THE PACIFIC OCEAN BASIN
Figure 64 shows hafnium distribution in the surface layer of Pacifie Ocean sediment (after Lisitsyn et al. 1980) relative to total non-carbonate and not-silicate content, in grams/tonne.

Box 1 = < 2g; Box 2 = 2-4g; Box 3 = 4-5g; Box 4 = 5-6g; Box 5 = 6-8g; Box 6 = >8g.

9.3 Testing the new model through isotope geochemistry

The new model requires the large-scale escape of radiogenic strontium during formation of the MORB reservoir in the mantle; and it is worth paying attention to the unusual evolution of the $^{87}Sr/^{86}Sr$ ratio in oceanic water (Figure 65). It is a peculiar fact that only since sometime in early Cretaceous or late Jurassic time, radiogenic strontium started being supplied in large amounts to the waters of the ocean. The $^{87}Sr/^{86}Sr$ ratio 150 Ma ago dropped to a level characteristic of the restite at that time. After that, it started growing quickly and has reached 0.7092 at present. This growth coincided with active seafloor spreading and tholeiitic volcanism (with low $^{87}Sr/^{86}Sr$ ratio in MORB). It would be natural to assume that continental erosion synchronously increased in order to compensate for the MORB contribution. But this assumption is hardly justified, because immense Cretaceous marine transgressions took place at the same time. Hence, considerable continental area was submerged and could not be affected by erosion. This submergence points to oceanic sources for the radiogenic strontium. It also correlates well with the interpretation of a huge outburst of radiogenic strontium from the mantle below the oceans during the most recent stage of Earth evolution (Figure 63).
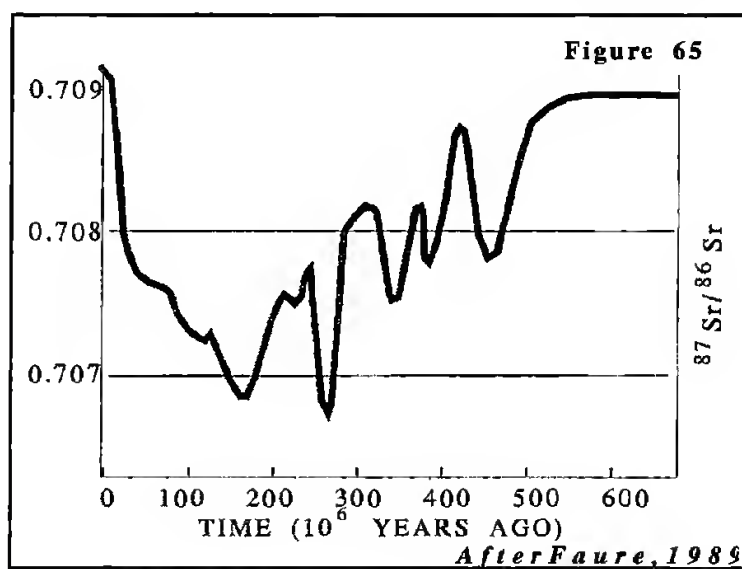

Figure 65 shows the variation of $^{87}Sr/^{86}Sr$ through Phanerozoic time. The curve is constructed from 768 analyses of marine carbonates in which there has been no change in strontium characteistics since deposition of its host carbonate.

It would be interesting to balance the contributions of radiogenic strontium from different sources and to prove whether the problem really exists. Recently it was shown (Palmer & Edmond, 1989) that neither continental erosion nor hydrothermal reworking of basalts in the oceans could provide for the increase in the $^{87}Sr/^{86}Sr$ ratio in ocean water, and that there should be another, still unknown source of radiogenic strontium in the oceans. Another possibility for escaped

radiogenic strontium, the diagenesis of oceanic sediments, has also been discussed (ibid.). More data are needed to elucidate this unknown source precisely. Our model implies that it should be in those parts of the oceans where the anomalous intermetallic mantle is close to the Earth's surface.

It is worth noting that any hypothesis for the release of additional strontium is unprecedented and totally unexpected from the traditional point of view, whereas its existence is undeniably implied by the new model.

Several years ago, as a crucial experiment for the Sm-Nd system, it was proposed to study ancient mantle garnets which, according to the new model, should have large (up to several tens of times) positive ε_{Nd} values. Unfortunately, it proved to be impossible at that time to publish this prediction on garnet composition because of the fierce resistance by reviewers. At the time, the prediction was of great topical interest, as there had been an absence of data on garnets. Since then, large positive ε_{Nd} values, up to several tens of times expected values, have appeared for garnets.

Reinterpretation of U-Pb systematics, which requires the dextral shift of the geochron with respect to the meteorite geochron, is valid only if the initial concentration of uranium on Earth was much larger than in meteorites. Otherwise, our planet would not have been enriched with respect to meteorites in the short-lived ^{234}U isotope. Therefore, the initial terrestrial point would not have shifted horizontally on the Pb-Pb diagram.

It is very interesting that, in principle, the hypothesis that the U concentration on Earth is about ten-fold higher than in meteorites can be tested with the aid of the isotopes of abyssal helium. In the new model, helium emission in rift valleys of mid-oceanic ridges is of super-abyssal origin. Helium is degassed from a substance which is extruded (or floats up) from the core-mantle boundary (Figure 47). Most probably, the isotopes of this helium flow are not distorted during their ascent and correspond to the isotopes of the terrestrial inner geospheres which had not been degassed earlier. If one could determine the original concentration and primordial isotopes of helium on Earth and add radiogenic ^4He from the decay of uranium and thorium, it is possible to obtain the modern $^3He/^4He$ ratio of 10^{-5} provided that the new model of the Earth is correct.

The main difficulty is determining the original He concentration. The trend of noble gases on the Sun-Earth diagram defines the mode of gas retention during planetary accumulation. From the helium ionization potential (23.58 v) it is possible to determine Earth's helium deficiency coefficient, but with a low precision of plus or minus a factor of ten. Arbitrarily, this coefficient is $5 \cdot 10^{-13}$. Also needed is the original helium concentration on the Sun. This quantity is produced by thermonuclear fusion and should be much less than at present ($5 \cdot 10^9$ He atoms : 10^6 Si atoms). According to common astrophysical estimates, about one-third of the original hydrogen has been consumed ($4H = {}^4He$). Thus, $1 \cdot 10^9$ He atoms :10^6 Si

atoms is the original He concentration on the Sun.[2] By the use of an expression, $He_E = He_S \times F$, where F is the deficiency coefficient, and He_S is solar helium, the original terrestrial concentration of helium, He_E, is about $5.0 \cdot 10^{-4}$ He atoms : 10^6 Si atoms.

The outlook on the original He isotopes in the solar system are very confusing. As a rule, thepresent $^3He/^4He$ ratio on the sun is used. This ratio is unlikely to be valid, however, because solar ^3He takes part in thermonuclear reactions. On the one hand, deuterium and protium interact producing ^3He. This isotope may then react according to the equation $^3He + ^1H = ^4He$. Therefore, the present-day He isotopes are likely to reflect fusion dynamics, and not in any way to indicate the original He isotope distribution.

In this connection, it is worth considering the helium isotopc distribution in iron and silicate phases of stoney-iron meteorites. The ^4He concentration in silicate phases is about 15 times higher than in iron (Figure 66) and amounts to $(2-3) \cdot 10^{-5}$ cm^3/g of rock. If the uranium concentration in the silicate phase is about $1.5 \cdot 10^{-2}$ gram/ton and Th/U ratio is three, then this phase should accumulate radiogenic helium at a rate of $2.36 \cdot 10^{-5}$ cm^3/g of rock during 4.5 Ga, thus matching precisely the observed ^4He concentration in the silicate phase of meteorites.

This agreement probably shows that both the silicate and iron phases originally had the same helium isotope distribution, but because of the decay of uranium, which is abundant in silicates and practically absent in the iron-nickel alloy, radiogenic ^4He started accumulating in the silicate phase, and the two phases on the ^3He-^4He diagram diverged.

Thus, one may conclude that iron meteorites with low contents of uranium and thorium have preserved the original helium isotope distribution of the solar system. In this case, the primordial $^3He/^4He$ ratio is 10^{-1}. Therefore, the initial He content on Earth ($5 \cdot 10^{-4}$ He atoms : 10^6 Si atoms) and the primordial He isotope distribution are determined. Assuming $^{238}U/^{235}U = 137.88$, Th/U = 3, and the present-day U content in the terrestrial interior of 10^{-1} U atoms : 10^6 Si atoms, which is ten times larger than assumed values for meteorites. When the amount of radiogenic helium accumulated during 4.5 Ga of Earth existence is taken into account, the $^3He/^4He$ ratio should be $2.7 \cdot 10^{-5}$ at present.

This calculated ratio agrees with that observed in oceanic rift valleys. Thus, the commonly used U concentration on Earth conforms to the present isotope distribution of abyssal helium, but exceeds the U level in meteorites tenfold. The internal consistency of the proposed model is affirmed by these data..

Moreover, if the He isotope distribution in iron meteorites corresponds to the primordial He isotope distribution on Earth, then this assumption inevitably implies the expansion of the Earth, because a planet of constant volume should have been melted completely by the heat produced from the quantities of Th and

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[2] *If one hypothesizes that one-half the Sun's hydrogen has been "burned," then the present He concentration would be 1.5 times larger than what is observed. Thus, any considerable error in this estimate is improbable.*

U required for evolution of the He isotope distribution from the original value in meteorites to the modern mantle value.

Figure 66

HELIUM ISOTOPES IN IRON
AND SILICATE PHASES OF
METEORITES:

• In iron   ○ In silicates
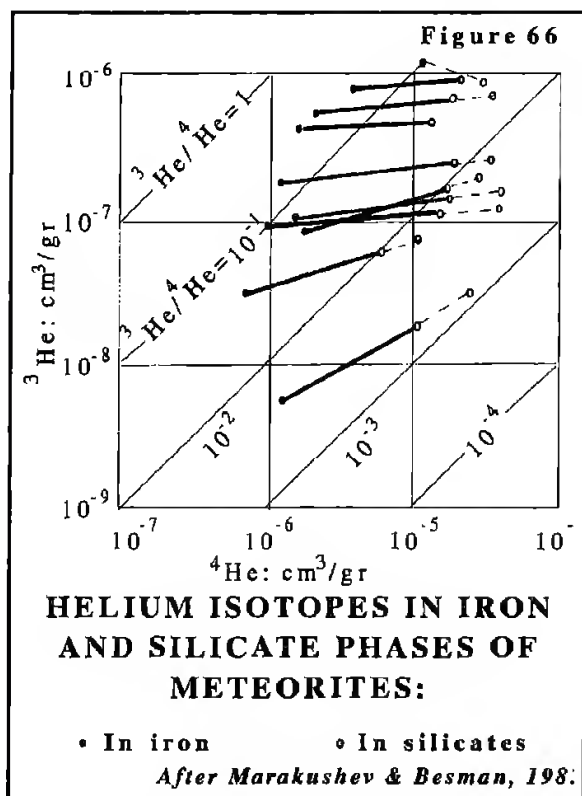*After Marakushev & Besman, 198.*

Figure 66 shows helium isotope concentrations in iron (black circles) and silicate phases (open circles) of chondrites

. Another approach to constrain the U concen-tration on Earth is to determine the deep heat-flow on the Moon. If a planet is tectonically active, expand-ing, for example, then there should be no equilibrium between its internal heat generation and surficial loss of heat. The Moon is tectonically dead, however, and equilibrium should exist. When the Earth and Moon were formed, both at the same time and distance from the Sun, they should, in response to the magnetic differentiation process, have had the same Th and U concentrations. Thus, it is possible to determine the terrestrial U concentration by measuring deep heat-flow on the Moon. The first such measurements on the Moon revealed heat flow several times higher than predicted by the chondrite model.

Finally, the $^3He/^4He$ ratio evolution from 10^{-1} to 10^{-5} considerably simplifies the situation with diamonds where $^3He/^4He$ ratios of 10^{-3} have been found. According to the new model, these diamonds are very likely terrestrial in origin.

9.4 Planetary water volumes vs. oxygen isotope ratios

One often hears the statement that considerable Earth expansion in the later stages of its evolution is precluded by the so-called water problem, in which the entire water mass is thought to have appeared at the earliest stages of the planetary evolution by catastrophic degassing. In point of fact, if the Earth had expanded in the Mesozoic and Cenozoic times, its entire surface, including continents, should have been submerged in the pre-Mesozoic. As this is clearly not so, the possibility of considerable Earth expansion is considered discredited.

However, the above reasoning is tied in to catastrophic degassing of an

Earth with a traditional iron core and a silicate mantle; and it regards water as the principal fluid that emerged from the interior, and hence that a major part of the hydrosphere must have formed very early.

By contrast, if degassing had occurred on a planet with internal structure according to the new model, the result would have been quite different. According to this model, free water would appear only in the degassing fluids when the silicate-oxide layer of the planet was completely formed. This most probably occurred at the end of the Archean, when the early, areal, granulite, anhydrous metamorphism was completely replaced by hydrous amphibolites.

Thus, according to the new model, the superficial hydrosphere had appeared and could permanently exist only from the end of the Archean. Since then, the hydrosphere has steadily grown. The scale of this growth in the Mesozoic and Cenozoic can be evaluated with the aid of oxygen isotopes.

Ocean water isotope distribution at present is usually taken as the standard: $\delta^{18}O = 0$ in seawater. There are many data (Hoefs, 1983) showing that this parameter was also zero in the Mesozoic and Cenozoic. However, marine sediments, e.g., cherts, carbonates, mudstones, are enriched in the heavy oxygen isotope; on average, $\delta^{18}O$ in sediments is $+30\ ^o/_{oo}$. If ocean water permanently loses the heavy isotope, and the water isotope distribution remains the same, there should be a steady reflux of heavy isotope to the ocean, should there not?

Juvenile ("magmatic") water is likely to have $\delta^{18}O$ about $+6\ ^o/_{oo}$, an appropriate figure for water in isotopic equilibrium with the terrestrial mantle at high temperature (in ultramafic rocks, $\delta^{18}O$ varies in a narrow range from $+5\ ^o/_{oo}$ to $+7\ ^o/_{oo}$, $+6\ ^o/_{oo}$ on average).

If we make the assumption that during the Mesozoic and Cenozoic, a 200-metre thick layer of marine sediments with $\delta^{18}O = +30\ ^o/_{oo}$ had accumulated, then a 1 000-m deep layer of juvenile water with $\delta^{18}O = +6\ ^o/_{oo}$ should be added to the hydrosphere in order to preserve the oxygen isotope distribution in the ocean water at the observed level. Thus, ocean volume would have had to increase approximately fifty percent during this period.

It is abundantly clear that this simple but stringent calculation invalidates the traditional concept. It is readily accommodated, however, within the framework of the new Earth model. This model requires a continual replenishment of hydrosphere as the Earth has expanded, and the modern oceans have widened and deepened. This relationship requires a continuing emission of juvenile water, where the traditional model relies on various forms of recycling.

CHAPTER X

ASPECTS OF PLANETOLOGY

This chapter is an attempt to find new ways and means for interpreting specific features of terrestrial planets on the basis that magnetic differentiation provided the inner planets with a primordially hydridic composition.

10.1 Implications for planetary chemistry

It is logical to assume that magnetic differentiation must have had some effect on the compositions of the inner planets. Evolving at different distances from the Sun, if the original conjecture is valid, the closer the planet is to the Sun, the richer it should be in metals with low ionization potentials. Conversely, with greater distance from the Sun, the proportion of hard-to-ionize elements should increase. After a fashion, this assumption may be illustrated by the proportion of elements on Earth relative to their quantities in meteorites, the asteroid belt being almost triple Earth's distance from the Sun. However, differences in terrestrial and asteroid concentrations are not a simple indication of differentiation of proto-matter in the zone of inner planet accumulation.

One such indication might have been derived from the studies of the composition of Venus' atmosphere by Soviet unmanned space probes. In particular, Istomin and others (Moscow, Institute of Cosmic Research) determined mass-spectrographically the concentrations of krypton, argon, and neon on various planets. The krypton readings proved to be at the threshold of instrumental sensitivity, but argon and neon reported at levels on which we can rely. These determinations showed that the $^{36\text{-}38}Ar/^{20}Ne$ ratio in the atmosphere of Venus was 7.5 ($\pm$ 2.5) against 1.7 in Earth's atmosphere. Because the ionization potential of neon (21.56 V) is much higher than that of argon (15.75 V), the systematics of magnetic differentiation anticipate the neon fraction of atmospheric gases to diminish faster than the argon fraction as the Sun is approached. The curves showing their concentrations should diverge and the ratio of $^{36+38}Ar/^{20}Ne$ increase.[1]

Thus, the behavior of the inert gases on Venus seems to be consistent

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[1] *In an exercise of this sort radiogenic argon (^{40}Ar) should be excluded, because its primary presence in the Solar system is inseparable from its secondary concentration from radioactive potassium (^{40}K), which has a much lower ionization potential. Furthermore, atmospheric ^{40}Ar may be affected significantly by K distribution patterns in a planetary lithosphere, as well as by the temperature regime of degassing (Kayser 1974).*

with the predictions of magnetic differentiation, and the concept may aid materially in interpretation of hitherto perplexing facts, one of which is the internal composition of the inner planets, the elemental makeup of which should be fully predictable. For example, uranium and cesium should be more abundant on Mercury, the planet closest to the Sun, while Mars should be much more richly endowed than other inner planets with mercury, platinoids, gold, and sulfur.

It is of critical importance, however, to evaluate correctly the original share of oxygen in the compositions of the inner planets, at least to the extent of being able to say they had "more or less" oxygen than Earth. Manifestly, the primordial share of oxygen may be largely responsible for the evolutionary pattern of planets through its controlling effect on the presence and thickness of the silicate-oxide shell, which acts as a thermal insulator for the interior. It may be said that primordial oxygen controls planetary thermal regimes. The high ionization potential of oxygen suggests that its contribution to primordial planetary makeup should steadily decline with lessening distance to the Sun, and rise with increasing distance. Hence, on Mercury, which has the least original oxygen and low planetary mass (the Earth has a mass 18.2 times that of Mercury), the silicate-oxide shell may be so reduced as to be unable to provide thermal insulation for the inner geospheres.

Let us direct attention now to the planets that are farther than the Earth from the Sun. Should the share of oxygen in the original planetary compositions increase with a greater distance from the Sun, one would expect a thicker silicate-oxide shell on Mars than on Earth. A still larger one must have occupied the inner geosphere of the primeval asteroid parent. The high degree to which meteorites are enriched in ionization-resistant elements (Figure 2) suggests that silicate minerals may even have dominated that body. Thus, stoney meteorites not only offer the best record of the mainly silicon-oxygen compositions in general, but also shed light on the average composition of planetary matter from the zone of the asteroid belt.

It is, thus, possible to evaluate average concentrations of elements on the Earth on the basis of their respective concentrations in meteorites, as has been shown in Chapter VII for potassium. Here, we will also try to evaluate mean concentrations of the radioactive elements, U, K, and Th on the Earth. But we will start by trying to explain why some elements (including Th) report outside the general field of points (shown bracketed in the plot of Figure 2 by two straight lines).

If the position of the main set of points is the recording of the different primordial compositions of the planets as determined by magnetic differentiation of the proto-matter, then any deviations from this regularity may be consequent upon subsequent redistribution of elements in the course of planetary evolution. Such deviations may be due to incompatibility between the compositions referred to for comparison, and the mean (primordial) composition of planetary matter in the zones compared. Significantly lower percentage abundances

(e.g., meteorites vs. the terrestrial mafic - ultramafic assemblage) can be due either to a more intensive rate of accumulation of the element in the outer geosphere (relative to the Earth in general), or to its lower concentrations in meteorites (relative to the mean value in the primordial body). It is geochemically absurd to suggest that in the mafic - ultramafic assemblage (1:3) of terrestrial rocks, concentrations of niobium, tantalum, thorium, cerium, phosphorus, and halogens could be 1.5-2.0 orders of magnitude above the mean composition of the Earth[2]. We have to assume, therefore, that these elements have been separated from the general set of points because of their lower concentrations in meteorities. This separation apparently happened while they were still in the primordial body. The ensuing problem is how to explain the pattern and to find the reason why meteorites have not produced specimens markedly enriched in these elements.

These problems appear impossible to resolve now; and we can only suggest that elements that fall outside the regular pattern may have been redistributed in the primordial body, and that rocks known to contain them, by virtue of their special chemical and physical properties, cannot survive a penetration of the Earth's atmosphere[3]. The validity of such an assumption

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[2] *Enrichment by two orders of magnitude is possible only in a mass that is less than 1 % of the mass of the entire planet (approximately the share of mass represented by the crust), and only under the condition that in the remaining 99 % of planetary mass concentrations decline to zero. However, the mafic - ultramafic assemblage (with the composition of 1:3) must closely approximate the outer geosphere the proportion of which, as a part of the overall mass of the planet, is at least several percentage points. In addition, the assumption that concentrations may be as much as two orders of magnitude lower throughout the mantle fails to confirm the apparent enrichment in the aforesaid elements in the deepest-sourced mantle magmas such as alkali basalts, kimberlites, carbonatites, and associated assemblages of alkalic- ultramafic rocks.*

[3] *Note the list of elements that are separate from the general trend include: Nb, Ce, Th, Ta, P, and halogens. This set is very specific and typical primarily of carbonatites, which are rocks that are exotic on Earth. However, if in meteorites carbon is several times as abundant as on Earth, and if the primeval body (or bodies) were subjected to carbonatite transformation, that process might have been widespread. Indeed, it could be the reason that the aforesaid elements are absent from silicates in the primordial body but concentrated in carbonatite-type rocks. Attention is due also to the thermal instability of carbonates. The temperature of magnesite decomposition, for example, at normal pressures is 373°C, and that of siderite is 282°C. This property may lead to their being rapidly ablated in the atmosphere of the Earth. However, it is impossible to judge whether terrestrial phenomena can be extrapolated to any planet that differs from the Earth in composition and, most likely, in mass, also.*

("incapacity for penetration") can be inferred in principle from such phenomena as "bright bolides" which, as a rule, never land as meteorites. Some bodies responsible for fire-balls are, according to the bolide watch, "aliens" from the asteroid belt.

By combining the reason that elements fall outside the general set of points in the plot (Figure 2) and their original redistribution in the primeval body of meteorites, we can obtain some grounds for believing that mean Th values in the asteroid belt is higher by at least an order of magnitude than its concentrations in meteorites that have been examined. This estimate was derived by moving thorium (in keeping with its ionization potential) into the axial zone of the general set of points. The Th ionization potential is such that its terrestrial concentration and those in the asteroid belt should be approximately equal. As a result, the original concentrations of Th on the Earth must have also been higher by an order of magnitude than those in meteorites. Uranium and potassium are in the left part of the plot (in keeping with their low ionization potentials (Figure 2) amid elements whose concentrations in the Earth accretion zone must be approximately one order of magnitude higher than in the asteroid belt. Therefore, mean uranium, potassium, and thorium concentrations must be, to a first approximation, an order of magnitude above their abundances in meteorites.

Given such estimates of the concentrations of radiogenic elements inside the Earth, calculations show that heat generation should be higher by an order of magnitude than the known geothermal flux[4]. This idea is not bizarre according to our systematics, because the Earth is expanding through decompaction of its core matter. Decompaction proceeds at a pressure of about 100 GPa and is, thus, an exceptionally energy-consuming process. Had the entire radiogenic heat been wasted to keep the Earth expanding, the dimensions of the zones of expansion would not have exceeded the widths of mid-oceanic ridges.

Based on the outlined cosmochemical patterns and allowing for more abundant U, K, and Th on the Earth than in chondrites, estimates of mean radioactive element concentrations on the Earth inevitably lead to the expanding-Earth solution, because a body with a constant volume, given such scales of radiogenic heat generation, would inevitably be molten today. This conclusion holds true even if conjectures on Th redistribution in the primeval body of meteorites were to prove false, because U and K yield most of the radiogenic heat.

The overall magnitude of ocean formation throughout Meso-Cenozoic time, if attributed to the concept of an expanding planet, requires a source of

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[4] *The general validity of our ideas of the magnitude of radiogenic heat generation inside the Earth can be verified on the Moon, see Chapter XI.*

energy much more powerful than radiogenic heating. Even the foregoing estimates of radiogenic element concentrations do not suffice. What other source of energy might the hypothesis of a primordially hydridic Earth have to offer? It is logical to turn to chemistry for possible solutions. Let us start with the earliest moments in the history of planet Earth.

If the rate of planetary compaction had been sufficiently rapid, it can be assumed that the interior of the Earth at a certain depth would no longer have been able to exchange heat with its surroundings. Then, as the mass of its solid body and its interior pressures grew concomitantly, the compaction process should have been adiabatic. Adiabatic compaction with rapid reduction of volume would lead to much higher temperatures.

Thus, a multifold volume reduction of the Earth[5] should release energy, which quite well could be sufficient to melt the entire planet. We therefore have to find some form of energy consuming mechanism that could be associated with compaction of the bowels of the Earth. In light of the hypothesis of the primordially hydridic Earth, this mechanism could be the endothermal reactions that comprise the formation of dense hydrides. This hypothesis is supported by Le Chatelier's principle of equilibria shifts, wherein higher temperatures always favor reactions that consume heat, reinforcing the endothermal direction of a reaction. Higher pressures under any particular set of conditions favor the formation of denser substances that occupy less volume.

As a result, the gravitational energy which materializes in the form of heat after compression might have been conserved in the body of the planet, being absorbed in endothermal hydride formation. The formation of hydrides was, in feedback fashion, stimulated by the growing pressure at the interior of the emerging solid body of the planet[6].

With time and radiogenic heating, the temperature of the planetary interior might exceed the threshold temperatures for typical hydride stabilities, causing them to dissociate, and hydrogen to be released. The energy stored as the energy of densification and chemical bonding in hydrides, when liberated again as heat, would be able to provide the energy base for tectogenesis in all its forms, the expansion of the Earth being just one. Radiogenic heat may only play a role as a trigger for the more powerful releases comprising

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[5] *The anomalous compressibility of hydrides would allow for such compaction, in principle (see Chapter V, 3). Additionally, a 5-fold expansion of the Earth at the geological stage of its evolution is suppported by geological data (see Chapter VII, 2).*
[6] *Within the framework of our model, an energy of about 10^{32} J is required for a five-fold increase of planetary volume. For retention of this amount of energy, it is necessary that, during the formation of Earth's rigid body, two thirds of its mass should accommodate endothermia, with a total heat assimilation of 400 kJ/ mol (for a mol of mass 35 g). This order of magnitude for enthalpy does not seem too high.*

the exothermics of non-explosive, hydride decomposition, which fuel general planetary expansion.

Exothermia apparently shifted into a higher gear when hydrogen degassing spread to the mid levels of the planet. Pressures in this geosphere are maximal, and hydrides are in their most compacted forms. Hence, an explanation is needed for the accelerated expansion of the Earth with time as the hydride core of the planet is being reduced (see Chapter VI, 1).

10.2 The new model of the Earth in light of the first and second laws of thermodynamics

The first law of thermodynamics reflects the principle of conservation of energy formulated as

$$Q = U + W, \tag{1}$$

where Q is the thermal energy applied to the system from the outside; U is the internal energy of the system; and W is the work applied by the system to its surroundings.

At an instant when no heat is applied to the system and external forces apply work to the system, the conventions of thermodynamics require that the work and heat be expressed with a negative sign. Here, the equation (1) takes the form:

$$- Q = U - W \quad \text{or} \quad W = U + Q \ . \tag{2}$$

The second law of thermodynamics states that all irreversible processes occurring in nature are accompanied by an increase in entropy and that nature knows no phenomena resulting in a decrease in the entropy of the material world surrounding us.

Thermodynamic systems can be considered "isolated" when they fail to exchange either energy or matter with their surroundings, "closed" when there is an exchange of energy but no exchange of matter, and "open" when the system exchanges both in energy and matter with its surroundings.

In order to determine the correlation of the new model with the first and second laws of thermodynamics, it is necessary to divide the entire history of the planet into separate stages of different thermodynamic characteristics. In this connection two stages can be clearly distinguished, first the protoplanetary stage, which witnessed the formation of the solid body of the Earth, and second, the planetary stage, the "records" of which are to be found in geological formations of various ages.

It stands to reason that we should view the problem from the time of collapse of the protoplanetary gas-plasma nebula (the Eneev-Kozlov model) when the radiation of energy to the outside becomes negligibly low (due to increased internal density) by comparison with the quantity of energy remaining inside the system. In other words, the protoplanet will be regarded as a thermodynamic system from the point in time when it acquires an "adiabatic shell."

From this moment on and throughout subsequent compaction of the protoplanet, it is considered a closed system experiencing adiabatic compression under the action of the force of gravity. The force of gravity is considered an external force from the viewpoint of thermodynamics. In order to justify this, the following reasoning can be offered. If the conventional idea that for each fragment of mass of a protoplanet, the force of gravity is an external force, then for the totality of protoplanetary mass, the cumulative force of gravity must, likewise, be an external force.

Therefore, at the compaction stage the protoplanet should be treated as a closed system. No exchange in substance is taking place. Work is applied to the system in the form of adiabatic compression without heat transfer. Because we can assume that the energy of gravitational compaction in this case is absorbed in the interior of the protoplanet by endothermal reactions (Chapter X, 1), formula (2) can be reformed using the enthalpy "H" which is, in fact, the "heat of generation" of chemical compounds:

$$W = U + H. \tag{3}$$

Let us insert the function G, the Gibbs free energy, the cumulative or total chemical potential of the system into formula (3), and, because $H = G + ST$, then

$$W = U + G + ST, \text{ or}$$
$$dW = dU + dG + SdT. \tag{4}$$

From this perspective, work applied by external forces should be accompanied by variations in the internal energy of a system, the Gibbs free energy, and the entropic term, "ST". However, our assumption as to the absorption of the energy of gravity-forced compaction by reactions of endothermic hydride generation allows us, hypothetically at least, to presume that the temperature in the system is invariable. From this presumption and, because at a constant temperature $dU = 0$ and $SdT = 0$, it follows that formula (4) can be reduced to:

$$dW = dG, \tag{5}$$

The basics of the science of thermodynamics teach that:
$$dG = VdP - SdT,$$
which at a constant temperature will have the form:
$$"dG = VdP" \tag{6}$$
With the apppropriate substitution, $dW = PdV$, formula (5) becomes:
$$PdV = VdP, \tag{7}$$

which actually reflects Boyle's law and consequently does not contradict the truth. This latter relationship may be advantageously represented in integral form,

$$\int_{V_i}^{V_f} PdV = \int_{P_i}^{P_f} VdP$$

where "i" and "f" are the corresponding initial and final magnitudes of the parameter used for integration. This notation implies that with variations of volume (left side) the pressure fails to remain constant, and obversely, a change in pressure (right side) leads to variations in the volume of the system (Figures 67, 68). This condition should prevail during the protoplanetary stage.
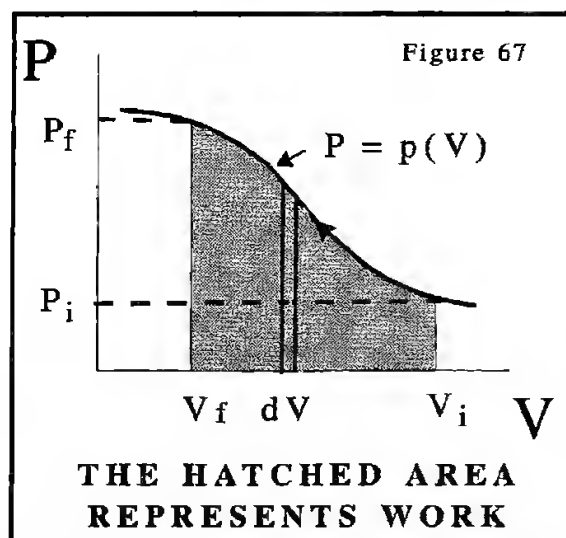
Obviously, it is fair to say that in the course of the protoplanetary stage of Earth formation, the work of the force of gravity, providing temperature remained constant, could be entirely converted to a cumulative chemical potential of the system as a whole. In the case of the initially hydridic compo-sition of the planet, the process was necessarily made evident primarily as increased chemical potential of hydrogen. This statement conforms fully with the first law of thermodynamics; and the said evolutionary stage also agrees with the second law of thermodynamics, because at that stage the protoplanet (as a thermodynamic system) experiences induced evolution under the influence of its environment (gravity forces being always external forces), rather than developing spontaneously.

The evolutionary stage is followed by the planetary stage in Earth's development. In this stage the energy stored in the interior of the planet during the preceding stage in the form of a cumulative chemical poential provides a major energy source. This energy determines the entire subsequent geological evolution of the planet. Radiogenic heat from the decay of long-lived isotopes, when compared with cumulative chemical potential, constitutes only a minor share of the energy balance of the planet. But it does play quite an important role as a "trigger" for involving the chemical potential of the Earth into active tectogenetic processes. From a thermodynamic point of view, radiogenic heat must be thought of as heat transferred to the system from its surroundings.

Figure 68

$$V = V(P)$$

**THE CHEMICAL POTENTIAL
(at constant temperature)**
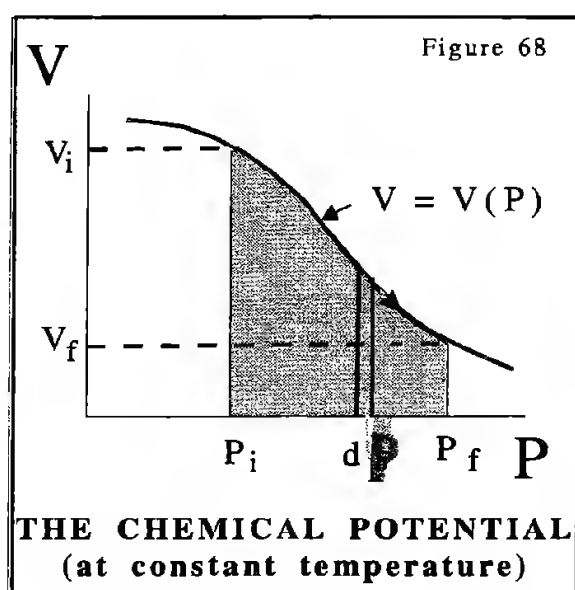
At this stage of its evolution the Earth should be regarded, in the context of our model, as a fully open system capable of extensive exchange in energy and substance with its surroundings. In the course of evolution the hydridic planet outgassing initially causes loss of more mass (quantity of atoms in conventional thermodynamic terms) than remains in its body. The limitation imposed by the first law of thermodynamics is mainly a concern that energy expended for proactive development of the planet should not exceed the reserves stored in its interior in the form of cumulative potential chemical and radiogenic heat energy from long-lived isotopes. Calculations show that the energy of gravitational compaction stored in the form of cumulative chemical potential is sufficient for enormous, episodic expansion of the Earth in the course of its evolution as a planetary body. The energy consumed in proactive processes, magmatism, metamorphism, folding and other tectonism, is extremely small compared with the quantity spent on expansion of the planet. In the context of substantial Earth expansion the proactive energy budget may safely be ignored.

When a system is fully open, there can be no limitations on it by the second law of thermodynamics excepting that all processes occurring within it must be seen to be accompanied by an increase in entropy of the universe. The entropy in the interior of a system can grow, remain invariable, or diminish depending on what irreversible processes may be occurring within it and any losses of entropy to the outside. It must be remembered that entropy is an extensive parameter which, like volume and mass, is characterized by being additive. Therefore, when loss of entropy by the passage of mass out of the system exceeds its incrementation as a result of activity within the system, the entropy of the system will tend to diminish. This peculiarity, which is inherent only in open systems, is of exceptional importance, because a system can evolve from chaos into order only in a regime of diminishing entropy.

Within the framework of our model the substantial escape of entropy to the outside is ensured by the high thermal capacity of hydrogen and the large scale of its degassing systematics.

It is likewise important to note that hydrogen is liberated in the interior of the planet at temperatures substantially above those at which hydrogen dissipates into outer space. The point is that, in the course of diffusion from

hotter to cooler zones in the planet, hydrogen undergoes an irreversible transfer of heat, becoming cooled to "absorb" the entropy of the system, and eventually dissipated from the system with substantially higher entropy than its initial endowment, due to the the exothermal decomposition of hydrides.

To paraphrase Ilya Prigogine's vivid expression, matter in executing an irreversible heat transfer in an open system, from hot to cool "degrades" (by increase of internal entropy), whereupon the system, per se, can evolve towards a greater order (because of its diminishing entropy).

The mechanism of evolution of the open system, when a heat transfer agent passes through it, is understandable if the entropy record it treated as "reduced heat": $\Delta S = {}^{\Delta Q}/_T$. It stands to reason that the lower the temperature at which heat transfer and mass transfer occur, the higher the entropy of the heat transfer agent escaping the system. Taking into consideration the additivity of entropy to be added or subtracted like other extensive parameters, it is intuitively evident that increased entropy in the heat tranfer agent should be matched by a reduction in entropy in the rest of the system.

To finalize our thoughts within the scope of our model, the Earth's hydrogen outgassing may have led to diminishing entropy of the planet over the course of its geological evolution. This is a major prerequisite for its advance to a higher level of order, a systematic increase of complexity of its structure through time.

Concurrently, the conventional view of the structure of the Earth allows for no more than minimal exchange of substance between the planet and outer space. The planet, therefore is treated as a closed system. A closed system that remains in a static state as to energy exchange with its host environment may experience diminishment of entropy, but only if the system cools. According to the traditional approach in which the ferrous core and silicate mantle are taken for granted, diminishment of entropy is hardly conceivable, because the radiogenic heat output alone would exceed total planetary losses even assuming the lowest values for U and Th among chondrite models (Lyubimova 1968) More general cooling of the planet would inevitably have been visible as reduced tectonism and magmatism. The molasse thickness record shows the opposite to have occurred: increased Phanerozoic orogenic processes as we progress from older to younger cycles, while oceanic basalt effusion since Cretaceous times has exceeded by many times the entire volume of magmatic rocks formed over the entire preceding history of the Earth.

If a closed system does not cool, no decrease in its entropy is possible and, accordingly, no explanation can be given for the evolution of the planet toward increasing structural order. Therefore, if a traditional model for the Earth fails to explain the evolution of the planet in terms of the thermodynamics of closed systems, the new model enables us to consider the Earth system to be open and self-organizing. Thus, in thermodynamic terms, this outlook exhibits a certain convergence between living organisms and the Earth as an evolving body.

10.3 Geomagnetism and the new model of the Earth

Through the centuries humanity has used the magnetic compass and, quite naturally, pondered the origin of the planetary magnetic field.   The earliest theory of geomagnetism attributed it to the permanent magnetization of the planetary interior. But when it became clear that the temperature at depths of only tens of kilometres exceeds the Curie point, the alternative idea was proposed: an electromagnet inside the Earth. However, this idea also has been discredited, because whether a mechanism exists to maintain strong electric currents in the Earth's interior during its entire evolution has remained unclear.

Since the beginning to the middle of the twentieth century, pyromagnetic effects, the Hall effect, thermoelectricity, rotation of a magnetized body, rotation of electric charge, magnetic storms, and other mechanisms have been suggested as the sources of geomagnetism. None of them adequately accounts for the geomagnetic field (Rikitaki 1968). In the mid-forties, the idea of a magnetohydrodynamic mechanism in the liquid iron core was proposed. This concept is predominant today; and many researchers consider it the final theory of geomagnetism (Rikitaki 1968; Yanovsky 1971; and others).

The westward drift of the main elements of the geomagnetic field at a velocity of 20 km/year is thought to confirm the dynamo theory. This drift is million-fold faster than any large-scale movement that can be deduced from geological data.   Thus, for all practical purposes, a magnetohydrodynamic interpretation precludes any influence of the Earth's rigid shell (Stacey 1972). The main features of the geomagnetic field originate in the planetary interior, and the core is thought to be liquid.   These precepts have led researchers to presume that secular variations of the field result from convection in the core.

However, the dynamo theory is in poor agreement with the traditional concepts of an iron core and a silicate mantle.   In particular, the very existence of active convection in the core appears to be dubious. If the convection is of thermal origin, then the source of heat in the iron core is incomprehensible. Radioactive elements are lithophilic; and no mechanism is known which might have segregated them together with iron and nickel.

Some scientists think that the heat source of convection may be the ongoing growth of the core. In this case, the heat would accrue from the potential energy of heavy particles settling in the gravity field. But this process is unlikely to have lasted for several billion years, because the velocity of precipitation of heavy particles strongly depends on the viscosity of the lower mantle, which in turn strongly depends on temperature.   The conventional concept of core formation implies excessive heat evolution and concomitant reduced viscosity. The process should have accelerated steadily from the beginning, culminated, and then declined rather early (Birch 1965; Tozer 1965).

Other hypotheses of the energy source also exist, but among all of

them, the persistent requirement for thermal convection in the core, in the traditional model of the Earth, is difficult to accommodate in view of the low thermal conductivity of the silicate mantle. No "heat machine" can be 100-percent efficient, and, thermodynamically, convection is conspicuously inefficient (Stacey 1972). Whatever heat is transmitted through the mantle should be greater by tenfold than the fraction that is converted into convective movement. Thus, a heat exchange problem is posed by the low thermal conductivity of the mantle. No "heat machine" can work without heat exchange.

Furthermore, the efficiency of a dynamo based on thermal convection is limited by the absolute heat flow from the interior. From the traditional point of view, in which no significant expansion of the Earth is contemplated ever to have taken place, the energy dissipation from the core cannot exceed either the total heat flow at the surface, or even most of it for that matter. This is because heat generation mainly occurs where the radioactive elements are concentrated. This is in the crust, which is believed to have collected almost all the radioactive elements from the entire mantle. Having this constraint in mind, a researcher has to attribute a high electrical conductivity to the core in order to increase its efficiency as a dynamo. Notwithstanding this constraint, estimates of such high conductivity are emphasized; and one is properly justified in being concerned that the electrical conductivity of the core has been overestimated. Paradoxically, to underestimate the conductivity leads to a still larger heat output. This is because increased electrical resistance implies a need for greater velocity of convective overturning just to maintain the required dynamo output. As a result, theoretical heat output is excessive, and the energy balance is completely destroyed (Stacey 1972).

Having the above conflicts in mind, many researchers have preferred to ascribe convection in the core to planetary rotation and to propose that the core does not exactly follow the mantle. However, some problems exist here too, as the shear coupling between the liquid outer core and mantle has to be secured by assuming some relief on the lower surface of the mantle (Rikitaki, 1968).

The hypothesis of the originally hydridic composition of the Earth-type planets opens new approaches to geomagnetism. For instance, this model broadens considerably the possibilities for thermal convection, because, first of all, energy transfers within the core should be orders of magnitude above the total surficial heat flow. Secondly, no heat exchange problem exists, since the conductivity of metals is so much above that of silicates. And thirdly, the very efficient heat transfer capacities of hydrogen are a major factor..

These controls on geomagnetism are parameters of interior morphology that imply an inevitability for different angular velocities of the core and mantle. Core rotation may be either faster or slower than the mantle because of interior radial mass movements. To illustrate, hydrogen degassing from the core should lead to angular deceleration of the mantle, and angular accleration of the core: $W_c > W_m$. On the other hand, the formation of

throats, as consequences of the same degassing, will lead to mantle acceleration and the opposite situation: $W_c < W_m$. The interaction of these two phenomena, manifestly, leads to complicated dynamics of relative inner geosphere rotation in the initial and intermediate stages of fold belt evolution. In the final stage of fold belt evolution, however, orogenesis leads to $W_c > W_m$, thus additionally complicating the pattern.

At other intervals of planetary existence, when degassing is negligible and the Earth is beginning to expand, significant deceleration of core rotation occurs with respect to the mantle: $W_c < W_m$ (T.M. Eneev personal communication). Then, when matter starts to be injected into the mantle on elongate rift zones (Figure 47), a much more efficient mantle deceleration leads to $W_c > W_m$.

Calculations show that during the entire span of Earth history, radial mass transport in the planet, as required by the new model, is certainly sufficient to provide for variations in the relative rotation of the core and mantle ten times greater than presently indicated by the westward drift (which is about 0.6 mm/sec). Furthermore, the inner and outer geospherical layers of the core should rotate with respect to each other. It cannot be doubted that complex dynamics in the core-mantle system facilitate the formation and activation of the dynamo which generates Earth's magnetic field.

Thus, the new model implies that the inner core, outer core, and mantle should normally have different angular velocities; and, moreover, that the core-mantle relative velocity changes its sign from time to time.

In the mid-sixties, T. Rikitaki, a patriarch of geomagnetism, imagined these schematics as the simplest explanation for geomagnetic reversals. Quite correctly, however, he decided this solution could not be accommodated within the traditional Earth model. The new model does not permit the deduction that each reversal directly results from a change of sign of the relative core-mantle velocity. However, it is likely that these changes of sign as well as any permanent variations of angular velocities between the inner and outer core and mantle do lead to extreme instability of core convection and, as the result, to geomagnetic reversals. The new model, by comparison with the traditional model, offers additional opportunities for magnetohydrodynamics, both as to the energy and the resultant dynamics of the process.

The new model also implies a new theoretical approach to magnetism, one that differs in principle from previous theories. Hydrogen, as already mentioned, disperses in metals and exists as a completely ionized plasma consisting of protons and electrons, both of which are able to move freely in metal. Thus, hydrogen escaping from the core, where hydrides dissociate, and hydrogen degassing should be regarded as a plasma flow. This mode of propagation within the rotating planet should be expected to lead to magnetic activity. From a general perspective, the new model should always produce a magnetic field.

Following from this reasoning, it would be natural to expect that the mantle will also take part in magnetic field generation, as it also experiences the flux of hydrogen plasma. The dimensions of magnetic anomalies on the surface are directly related to the depths of the anomaly sources. Therefore, the mantle sources of the field should be reflected by regional features with dimensions from several hundred to 3 000 kilometres in the spectrum of magnetic anomalies. By contrast, if the field is generated only in the core, anomalies of these dimensions should be absent.

Lengthy observation of the vertical component of secular variations of the magnetic field at the Caspian center definitely point to the existence of well-defined anomalies with characteristic dimensions of 1 500 to 2 500 km (Pochtarev 1978). We are, therefore, on safe ground to state that the Earth's mantle also takes part in generation of Earth's magnetic field, a statement that is fully compatible with the new model.

There is an almost universal belief that paleomagnetic data preclude any significant expansion of the Earth. This conviction is rooted on paleolatitude considerations, and these are based on the a priori assumption that the geomagnetic field has always been a dipole. In other words, the field can be approximated by a magnetic dipole which resides in the planet center and is very small in comparison with Earth's diameter. Without the dipole attribution, paleolatitude interpretations lose their credibility,

However, the dipole concept is incongruent with the new model, because the model predicts that in the past, the hydrogen-rich core had occupied a much larger internal sector of the planet than at present, and hence was much nearer to the surface. Furthermore, the outer "liquid" core, where the field was generated, was formerly a rather thin shell, whereas this layer now occupies more than 95 percent of core volume (Figure 29).

Under these conditions, it is rather unlikely that the geomagnetic field could always be adequately approximated by a small dipole. Rather, the field structure in the past could have been better described as a large permanent magnet or electromagnet with a length comparable to Earth diameter. Today, the following formula is used: $\tan I = 2 \tan \Phi$, where I is inclination and Φ is latitude. This expression is valid for the dipole field which, according to the prevailing view, had existed at least since the beginning of the Phanerozoic. The new Earth model implies that the ancient field was different and that the difference between the dipole and actual field steadily increases backward in time. Therefore, paleomagnetic objections cannot be accepted and, in preparing to analyze paleolatitude data, it is necessary first to compute the global distribution of paleoinclinations within the new model and to apply the inclination-latitude law at different stages of planetary evolution.

The position of the magnetic pole, when averaged over ten thousand years coincides with the geographic pole. Therefore, the dipole axis must coincide with the axis of rotation. The displacement of ancient

magnetic poles with respect to the modern rotational axis (geographic pole) is usually accounted for by continental drift. The new model offers new opportunities for continental drift (for detail, see Chapter VI. 5).

However, new data on mantle tomography put strict constraints on large-scale horizontal movements of lithospheric plates. At the same time, the new model offers an opportunity to link planetary expansion and displaced paleopole positions. Pole displacements must have occurred if the planet had expanded significantly, and if the expansion had not been symmetrical with respect to the rotational axis (Figure 69).
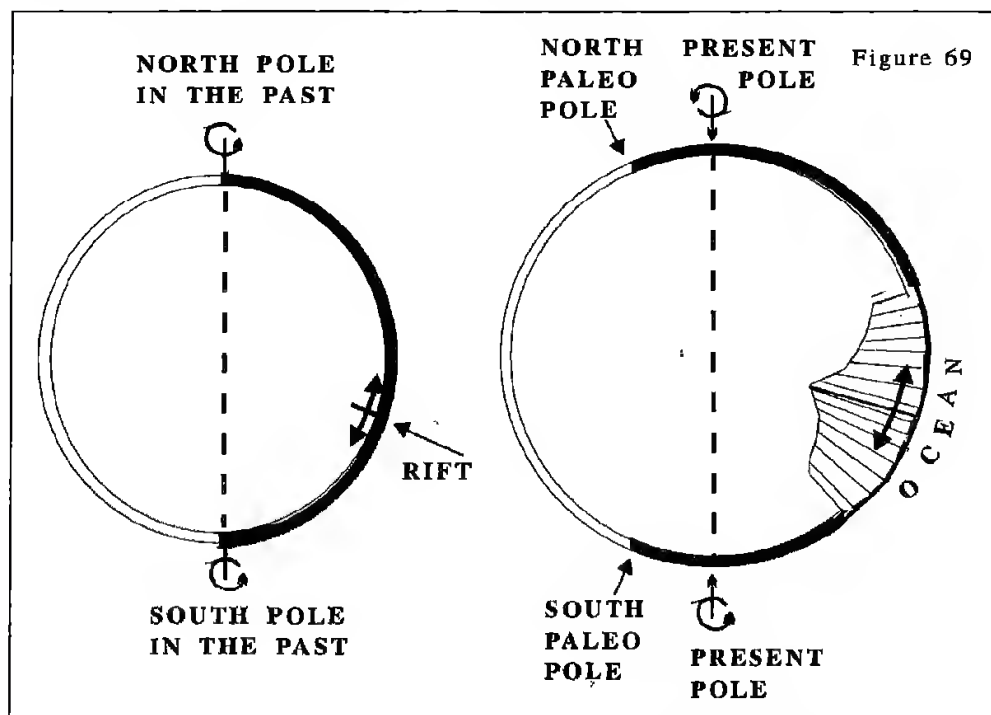
A DIAGRAM ILLUSTRATING THE DISPLACEMENT OF THE PALEOPOLES BY EARTH EXPANSION

Ocean opening is shown to coincide with paleopole displacement as the Earth expanded. The arc length (from rift to north pole in the past) equals the length of arc from the boundary of the ocean to the north paleopole, and likewise to the south.

In principle, it is possible to test the above hypothesis. If polar wandering actually resulted from Earth expansion (Figure 69), one can perform a "retrograde" computer simulation using maps of oceans and closing the spreading zones stepwise for different values of the terrestrial radius. By this method one obtains a coherent pattern of magnetic pole displacements with respect to the rotational axis, the orientation of which is presumed to be constant. This pattern should lead to a better agreement of paleomagnetic and paleoclimatological data. Of course, before starting this simulation, it is necessary to compute the magnetic field parameters within a framework of the new model, as previously mentioned.

### 10.4 Interpreting the structure of the terrestrial planets

Two major styles of evolution can be detected on the primordially hydridic Earth: active development and passive-aging. Active development is consequential upon hydrogen degassing, when internal planetary structure evolves and surface structure is created. Passive aging takes over as hydrogen reserves are depleted, tectonic activity wanes, the planet loses its magnetic field, atmosphere, and hydrosphere (provided it had the last two, of course).

Present-day diversity among the inner planets (Table 16) must be due to disparaties in their respective evolutionary histories. The lengths of their histories depend, other factors being equal, mainly on the original mass of the planet. The higher the mass of the body, the longer the period of degassing and active development.

				TABLE 16	
PHYSICAL CHARACTERISTICS					
OF THE INNER PLANETS					
PROPERTY	**MERCURY**	**VENUS**	**EARTH**	**MOON**	**MARS**
Mass (in Earth masses)	0.055	0.816	1.000	0.012	0.107
Mean density (g/cm³)	5.5	5.2	5.5	3.34	3.9
Speed of recession (km/s)	4.3	10.4	11.2	2.37	5.0
Period of rotation (days)	58.65	243.2	1.00	27.32	1.025
Magnetosphere (outer dipole)		?	+	-	-
Hydrosphere		-	+	-	-

The internal structure of planets with undepleted hydrogen reserves should correlate with the structures of the Earth. That is to say, they should have compact hydridic cores of high mean densities, whereas fully degassed planets should be much less dense. This is the explanation of the high density of larger planets like the Earth and Venus, and the much lesser densities of minor planets like the Moon and Mars. The hydrogen resources of the latter have been fully depleted, and today they are metallic spheres composed of oxygen-free silicides covered with a silicate-oxide shell (Figure 70)

The exceptional case of the small planet, Mercury, which nevertheless has high density, and consequently a disproportionately large core, can be attributed to its particular position as the planet closest to the Sun. As a result, it must have the lowest oxygen concentration and the thinnest silicate-oxide shell. If a shell is too thin to maintain the thermal insulation of the interior, the planet's resultant rate of evolution should be very slow, and it should be able to retain its hydridic core for a long time. This behavior is because the planetary heat is consumed so efficiently that overheating of the interior does not exceed the critical temperatures of hydride stabilities.

Figure 70
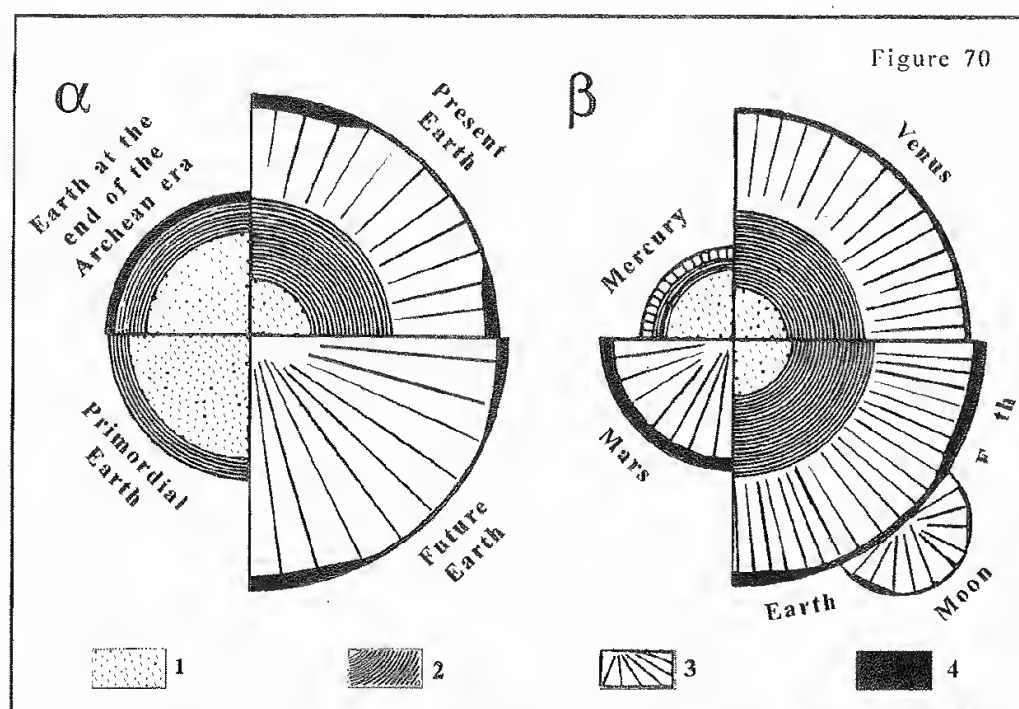
1) *Hydrides;* 2) *Metals with dissolved hydrogen;*
3) *Metal alloys and intermetal compositions;* 4) *Silicates and oxides.*

EARTH'S INTERNAL STRUCTURE AT VARIOUS STAGES

(α) *evolution of the internal structure of the primordially hydridic Earth.*
(β) *compares the present internal structure of Earth with Mars, Venus,*
  Mercury, and Earth's moon.

In terms of our hypothesis the planets that are capable of possessing a magnetic field arc exclusively those planets that have not lost their hydride reserves and are still at the stage of active hydrogen degassing. Thus, neither the Moon nor Mars fulfill these requirements, facts that are well supported by direct measurements. However, magnetic fields should have been present during their active stages of evolution along with concurrent hydrogen degassing. Dipole magnetospheres must arise from the rotation pattern of planets. The rotational speed of Mars is fairly close to that of the Earth. The Moon in the past must have rotated at a much higher rate and only later decelerated due to tidal friction. Hence, these planets may have had dipole magnetic fields in their active stages, and its record may occasionally have been preserved in the form of residual magnetization in the rocks. In addition, such records would also contain information on the periods of reversals of the magnetic poles.

The reason for the absence of an external magnetic field on Venus could be its rotational velocity, which is less than 0.5% of Earth's velocity. This means that the essential requirement for charged particles to be flowing

in a torroidal ring in Venus' interior is absent. The field of magnetic flux, therefore, cannot reach outward far enough to create a global exterior magnetosphere. Apparently, Venusian magnetism is fully localized in the interior, although it still t has not been ruled out that magnetic activity on Venus may be detected by examining its surface.

The dipole magnetosphere reacts on the environment at the surface of the planet at the same time as it screens out the corpuscular radiation from the Sun and conditions the stability of the ionosphere which absorbs ultraviolet and X-rays. The potential for photodissociation of water and for the dissipation of hydrogen from the planet are greatly reduced by the magnetosphere's effects. The dipole magnetic field should in one way be contributing to the emergence and volumetric growth of the hydrosphere. No hydrosphere can appear on Venus, because the planet has no external dipole field. On the other hand, as discussions of the reasons for the anhydrous regime of the Archean Earth have suggested, appearance of water in endogenic fluid emissions, and finally, a hydrosphere, could only happen if petrogenetic elements in the outer geosphere of the primordially hydridic planet had been fully oxidized. However, in a regime of magnetic separation less oxygen should have been retained by Venus, and even less by Mercury, than the Earth. Hence, the interpretation of "dryness" for these planets must be attributed to oxygen deficits in their original compositions.

Let us take up Mars again. It faces no danger of becoming "dry" for lack of oxygen, as it is situated farther from the Sun than Earth. If Mars had a dipole magnetic field at the stage of active development, it could also have had a hydrosphere that was lost at the stage of passive aging. Very likely, water on Mars has been conserved in tremendous quantities in the upper levels of the crust as permafrost. Mars' size is small by comparison with our planet, having a mass only 0.107 the mass of the Earth. Hence, its active stage of development must have been much shorter than the Earth's; and it must have terminated during Earth's early history.

A hydrosphere on the Moon is unlikely, because its small mass allows gases to dissipate easily into space. Thus, the Moon can be said to have never had any water even at the stage of active hydrogen degassing.

From our position, the kinds of tectonic structure found on a planet depend on its size. Planetary expansion at the active stage of development is controlled by the degree of compaction of its interior hydrides. It seems logical to assume that compaction of hydrides depends on pressure, which is determined by planetary mass: the more massive a cosmic body, the higher its pressures, the degree of compaction in its interior, and the breadth of its expansion at the stage of active development. Conversely, the volumetric growth of small planets with lower interior pressures and less-compacted hydrides should be less extensive.

Planetary expansion splits the lithosphere in parallel, linear extension

fractures. These originate as tectonogenes, aligned, linear, and extended; and they explain the "belt-like" arrangement of tectonic structures. These zones of tectonic relaxation later transmit most of the degassed hydrogen. If the planet is small and its expansion is therefore curtailed, the flux of hydrogen, in the absence of extended relaxed zones, is likely to occur on an irregular pattern with pipe-like tectonogenes and predominantly oval and ring-shaped tectonic structures.

This explanation gives us a possible reason for the differences between the surfaces of the Moon (with predominantly ring-shaped structures) and the Earth, with its chain-like systems of mountains. Mars, with a median size, occupies an intermediate position, and it is found to have both linear and ring-shaped structures, thus conforming to the above thesis. Manifestly, Venus should be expected to show more belt-shaped tectonic forms than Mars does.

Let us discuss some of the properties of the active stage of development of the primordially hydridic Moon. If its development had been fully controlled by hydrogen degassing, the evolution of its regime of endogeny would have followed the same pattern as on Earth (Figure 29), a progressive differentiation of the hydrogen flux into discrete jets and their subsequent coalescence into "channels" as the mantle thickened at the expense of the volumetrically-reduced, hydrogen-rich core. The silicate-oxide shell of the Moon (most of its mass) must have formed at the earliest stage of degassing, when oxygen was expelled from the planetary interior by the all-pervasive hydrogen flux. As the flow broke up into jets, the Moon's surface became pockmarked with numerous craters, that undeniably show features of past volcanic-plutonic processes. As a result, there emerged early in that stage the lunar "terrae," those peculiar light-colored regions that once covered the entire surface of the Earth's satellite. As the core dwindled and the mantle grew, numerous, fairly small jets merged into larger channels, which then produced the lunar "maria" at their points of emergence. Widespread melting of the silicate shell can be attributed to more intense heat from the concentration of hydrogen, the heat-transfer agent, into restricted channels.

There are some data now attesting to the prevalence of anorthosite as the component responsible for the lighter shades of the terrae. Early suggestions of an anorthosite composition of the Moon's crust were set aside, after accumulating data favored an reinterpretation of mainly gabbro-anorthosite composition. We can offer a different point of view.

First, seismic observations on the Moon have apparently failed to trace the crust - mantle interface, but show instead the base of its silicate shell, which is seismically estimated to be up to 60 km thick (Driscoll 1972; Taylor 1975). This figure is based on some proportionalities between Moon and Earth volumes and diameters of the two planets. Additional evidence comes from the latest seismic data from the Moon, where the velocity of seismic wave propagation below the 60-km layer is about 7.6-7.7 km/sec

(Vanyan & Galkin 1977; Taylor 1975). Such velocities are close to the values determined in the iron - magnesium - silicon alloy for the pressure $5 \cdot 10^8$ Pa and above (Figure 49).

Second, in the light of magnetic separation, the Moon, like the Earth, the metals magnesium, silicon, and (to a lesser extent) iron, must be the dominant ones, with aluminum and calcium subsidiary. In that case, anorthosites and gabbro-anorthosites in the Moon's silicate shell should be also auxiliary. And, if they are widespread on the surface, they must give way at a comparatively shallow depth to rocks of the werhlite - lherzolite peridotites that must comprise most of the silicon-oxygen shell of the Moon (Table 9).

The mean density of the Moon is 3.34 g/cm³. This value severely limits the choice among alternative compositions for the Moon generally. The Moon cannot be chondrite, because chondrites are much denser. As for such rocks as pyroxenites and peridotites, which have mass corresponding to the mean density of the Moon, the bulk of its volume can hardly have such compositions, because there is no way for garnet, spinel, and other dense mineral phases to have formed in the first place in the planet's interior. We might assume that the appearance of the eclogite assemblage of minerals with depth was restricted by low concentrations of aluminum; but this assumption is not limiting, because the abundances of the element in lunar basalts (6.0-6.5 wt-%) suggest that, even after the melting of the anorthosite components of the lunar crust, there should have been enough of this element in the planetary interior to produce sufficient garnet to raise the density of the rock above the mean density of the Moon[7].

Interestingly, basalts of the lunar maria have densities higher than the mean density of the Moon (Taylor 1975). Furthermore, at a relatively shallow depth, according to experimentation (Ringwood & Essene 1970), the basalts must grade into a 3.74 g/cm³- dense eclogite. This experimentation provides support for the suggestion that the Moon's interior includes an eclogite component. While still allowing for its major pyroxenite-peridotite composition, the composition is in conflict with the Moon's known low mean density.

Our hypothesis of a primary hydridic body offers an explanation for the anomalous composition. It allows for a relatively low-density, oxygen-free composition of magnesium (major) and iron (minor) silicides (Figure 49) beneath the high-density outer shell of the Moon. According to our model, the lunar mascons[8] can be attributed to thickness variations in the dense silicate layer formed as a result of oxygen expulsion from the interior

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[7] *2.5 wt-% Al could produce 20% garnet of the pyralspite series and increase rock density from 3.3 to 3.46 g/cm³.*

[8] *Ed. note: Mascon (MASs CONcentration) is a term applied to geophysically-observed, dense masses of unknown nature that are buried in the thick lunar crust. Conventionally they are considered Bouguer anomalies caused by post-uplift basaltic infilling (pers. comm. P.D. Lowman, Jr., Goddard Space Center).*

of the planet early in its history by a still-uniform hydrogen flux that had not then coalesced into jet channels. However, by virtue of the properties of hydrogen, the component channelways of the ubiquitous flux must necessarily have exhibited widely varying intensities. Variation logically explains the irregulat distribution pattern of oxygen in the Moon rocks. A zone of maximal hydrogen purging produces a thick silicate layer. A thicker silicate layer, being denser than the underlying silicides, creates a positive gravitational anomaly. Resurgent hydrogen flux would tend to reenter earlier-formed channels and to remain in them, thus, amplifying the density contrast of the growing mascon. It is precisely these zones that experience the most heating from ambient hydrogen, the potent heat-transfer agent, and over time selectively release the hydrogen and its former heat burden.

It is no coincidence that lunar maria, which are produced by the melting of the silicate shell at hydrogen escape channels, are conjoined to mascons. Such channels include Mare Imbrium, Mare Serenitatis, Mare Crisium, Mare Nectaris, Mare Humorum, Mare Orientale, and Mare Marginis. But a mascon may also exist without any connection to a mare. This is the case where the mascon did not inherit the hydrogen flow after it coalesced into channels. Such is the "Hidden mascon" on the far side of the Moon. Finally, a mare can form without any connection to a mascon if a sufficiently strong jet of hydrogen erupts (for tectonic or other reasons) in the lunar outer shell, where only a thin silicate layer is present, as, for example, at Mare Fccunditatis.

Figure 71
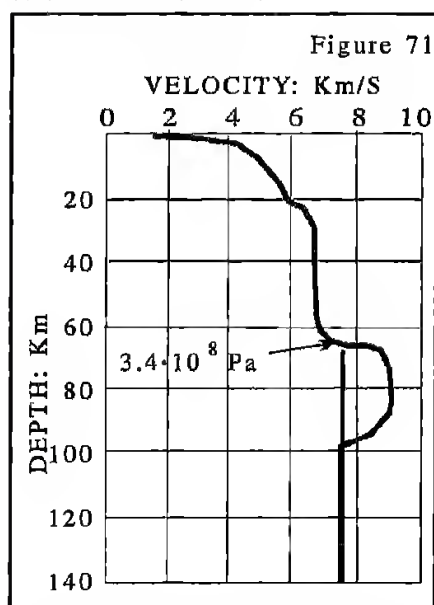
VELOCITY: Km/S

THE VELOCITY PROFILE FOR SEISMIC P-WAVES IN THE OUTER SHELL OF THE MOON
(after Taylor 1975)

Note: In Figure 71 the spread in the 60-100 km depth range represents the discontinuity of the high velocity layer.

Thus, in our concept lunar mascons occur where the base of the silicate shell is deeper than normal and the silicate shell is slightly denser than the intermetallic silicides beneath it. This model of the mascon, which was proposed in the author's first book on the subject (Larin 1975) required further elaboration. Seismic observations had shown the presence of a "high-velocity layer" inside the Moon at depths ranging from 65 to 90 km (Figure 71). Velocities rise abruptly to 9 km/sec suggesting a comensurately higher density. There being some indication that the high-velocity layer is laterally discontinuous, researchers (Taylor 1975) argue that

lenses of this high-velocity (and high-density) material occur at the base of mascons (Figure 72a). In light of our ideas, this explanation appears valid and may explain the limited distribution of this layer vertically and laterally. We favor the view that the high-velocity layer represents a zone within the silicate shell which shows evidence of pressures sufficient for dense mineral phases,[9] and is limited from below by the surface of the intermetallic sphere (Figure 72b). If we assume a silicate composition for the entire Moon and attribute the phase nature to the high-velocity layer, it is unclear why this zone has a limited distribution depth-wise.

It is noteworthy that the Moon's interior to a depth of 60 km and deeper was originally thought to have velocities of about 9 km/sec. This conformed to the traditional notion of a silicate composition for most of the satellite. This velocity, however, fails to satisfy our concept, which requires the layer to be composed of silicides with much lower seismic velocities of about 7.5 km/sec (Figure 49). The discrepancy between theory and fact posed a serious danger to the whole hypothesis, the more so as the author saw no possible compromise. Having no reason to doubt the validity of the experimental seismic data obtained by direct lunar observations, the author had to contrive various "multiplying factors" to salvage at least some aspects of the hypothesis. Then came new information indicating that seismic waves registered from sources spaced greater than 1 000 km apart (for deeper seismic viewing) showed that the Moon's mantle velocities are 7.6-7.7 km/sec. The 9.0 km/sec value proved correct only for a particular shallow horizon of lateral discontinuity. This new information *does* conform to our precepts and, by contrast, contradicts the traditional point of view.

As previously pointed out, the morphology of tectonic terranes is interpreted as a function of planet size. Size is the factor believed largely to control the internal dynamics of the tectonic process, because the pressure at the entrance to the tectonogene can prove insufficiently high for the compaction of "hydrogen-saturated" metals. For example, if the thickness of the silicate shell on the Moon is less than 100 km and its gravity field is 0.16 of the Earth's, the pressure at the estuary of the tectonogene, at the base of the silicate-oxide sphere, will fall within a range of 0.3-0.5 GPa. On Earth the comparable figures are orders of magnitude higher. Apparently, under such pressures on the Moon, either throats could not form at all or the process was greatly inhibited. In any case, where only a thin silicate layer is present, it is hard to imagine that an asthenosphere could either form or persist. For this reason the Moon could not have experienced horizontal tectonics to any

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[9] *According to experimental data (Ringwood & Green 1972), transformation of a pyroxene-plagioclase (gabbro) mineral association in pyroxene-garnet (eclogite) starts with a pressure of 0.34 GPa (at 1 100°C in dry conditions). Inside the Moon, with the mean density of the silicate shell of 3.3 g/cm^3, such pressures are attainable at a depth of 65 km.*

degree, a consideration which may account for the total absence of fold structures on the Moon.

Mars is another body that is much smaller than Earth (by a factor of 9.35 in its mass, and 1.89 in its radius). Folded structures on Mars could become manifest at much lower scales of energy input than terrestrial ones.

Horizontal motions on Venus could in principle be as strong as on Earth, its size being nearly the same. But Venus has a dense atmosphere, rich in carbon dioxide, which is responsible for greenhouse effects that raise the surface temperature by hundreds of degrees. Hence, Venus' asthenosphere should be much closer to the surface and much thicker than on Earth. Possible consequences would include: rapid isostatic levelling of topography, broader fold belts (given the same lengths as on Earth), less prominent thrusting, and abundant volcanic eruptions.
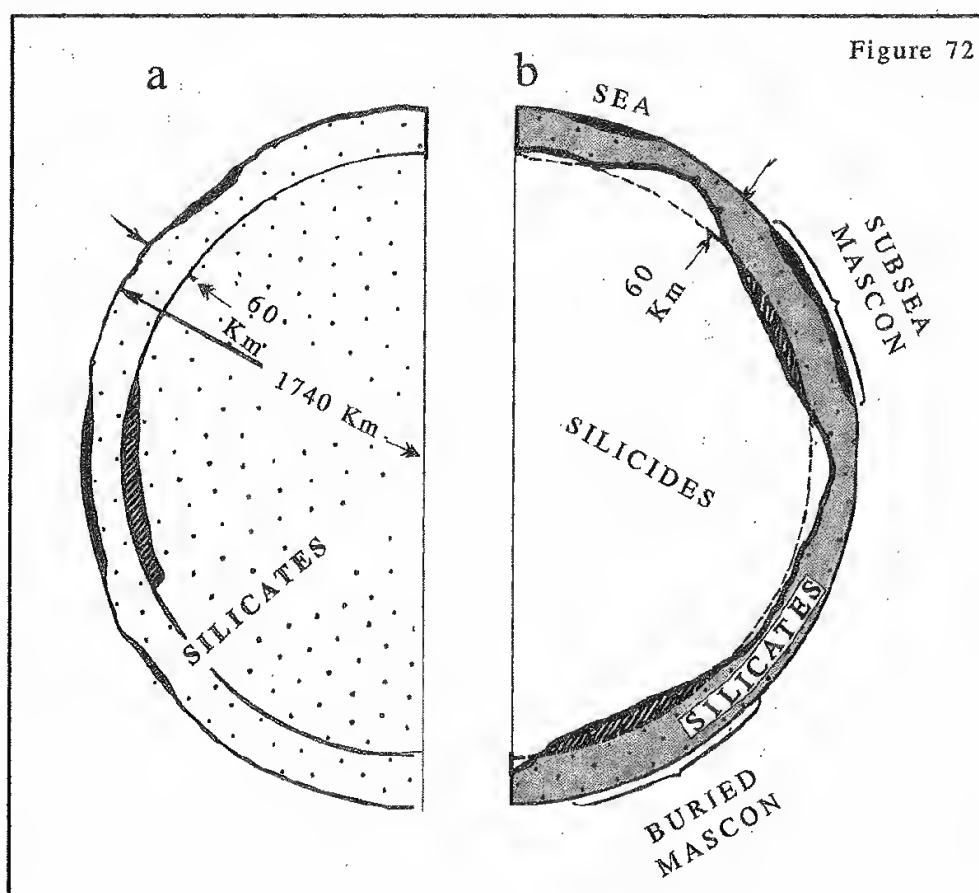

Figure 72 THE MODEL OF LUNAR STRUCTURE

a) *Traditional view: silicate planetary composition (after Taylor 1975)*
b) *New model: primordially hydridic composition. Hachures indicate the lenticular zones of seismic high velocity, which is due to dense mineral phases in the basal part of a thickened silicate shell.*

From detailed studies of Venusian radar data involving its polar regions to 30° latitudes vast, areas of "diffuse" reflectivity are in evidence. The surface seems to have originated as a plastic medium that has spread outward (plastic spreading, after Sukhanov 1986; Sukhanov & Pronin 1989). Complementary zones of subduction have not yet been found. A.L. Sukhanov has suggested (personal communication) that the data may imply essential expansion of Venus.

The passive stage in the evolution of the inner planets may show one common and distinctive feature; they must have had similar original compositions and abundances of radioactive elements, which should be, by an order of magnitude, higher than in chondrites. Since the Earth and Moon both formed at the same distance from the Sun, this should be especially so for them. However, at the passive stage, when a planet is tectonically dead and has lost all its heat-transferring agent, hydrogen the generation of radiogenic heat must lead to intense interior heating and to melting of enormous regions. Thus, the passive stage may have a characteristic and unique magmatic signature. Its unique character is due to virtual absence of volatile elements. These are known to play a decisive role in differentiation within magmas. Consequently, the magmatic activity at this stage would act together to cause homogenization of the melted volumes. Prominent remelting of the silicate shell would destroy the structural and tectonic framework of the planet that had been generated in the active stage. Thus, everything ever created at the active stage (ores, rocks, structures, channelways, etc.) may then be exposed to meltdown. We suggest calling this process *"destructive magmatism."* It would naturally first affect small planets on which the active stage had been completed early, but on which radiogenic heat generation was still comparatively intense.

Apparently, the Oceanus Procellarum and some other dark areas on the Moon might have developed from destructive magmatism. If our theory holds true, these regions can be expected to have generated the youngest magmatic formations ever seen on the Moon. These will be distinguished by low differentiation (petro- or geochemical) and will carry no traces of stable residual magnetization, because the magnetic field is missing at the passive stage.

Quite possibly, melting processes within the lunar body are still in progress today, if we may judge by the low-order seismicity of the lunar interior. This phenomenon, however, is due to the state of the silicate shell. If the shell is severely damaged (e.g., by large-scale, explosive cratering), the magnitude of melting would be reduced and localized deeper inside the planet. Moreover, the generation today of radiogenic heat is barely one-half that of three billion years ago because of the natural "decay " of radioactive elements.

Mars is much closer to the Earth than it is to the asteroid belt, hence, its radioactive element concentrations should be closer to terrestrial than to meteoritic. Therefore, in its present passive stage, this planet may be in danger of destructive melting. Mars is larger than the Moon and, in addition,

by comparison with the Earth and Moon, has a proportionally larger silicate-oxide shell. It would be interesting to know what form melting would take on that planet and whether Mars' giant volcanic edifices, several hundreds of kilometres wide at the base and dozens of kilometres high, may express one of these possible forms. Such structures could emerge only under conditions of low explosivity, that is, in the absence of volatiles in their magmas. This condition appears typical of the passive stage.

Next to be discussed is another argument advanced against our hypothesis. If the primordially stoichiometric composition of hydrides were assumed to take the form of MeH_2, and if the mean atomic mass of metals is 32, then in the course of its evolution the Earth should have lost about three to four percent of its mass in the form of hydrogen, approximately $2 \cdot 10^{26}$ g. This amounts to 1000 times the hydrogen resources in the hydrosphere; a deficiency that cannot be demonstrated.

We can supply a very short answer to this objection. Hydrogen has, indeed, dissipated from the planet. Dissipation rates in planetary atmospheres depend on the temperature of the exosphere and the recession speed which, in turn, is controlled by the planet's mass and mean density and by the molecular mass of the gas. Table 17 lists dissipation rates for a variety of gases (assumint fresh supplies of gas are not supplied to the atmosphere). These data show that hydrogen from the atmospheres of terrestrial planets is easily lost.

DISSIPATION RATES FOR SOME ATMOSPHERIC GASES

TABLE 17

PLANET	TEMPERATURE OF EXOSPHERE K	CRITICAL LEVEL Km	LIFE OF MEMBER (YEARS)			
			H	He	D	N_2 , CO
VENUS	2000	600	10	10^5	2×10^{21}	1×10^{38}
EARTH	1800	550	50	10^7	1×10^{29}	3×10^{50}
MARS	1000	1000	0.4	10^2	1×10^{10}	1×10^{17}

The time it takes for the gas to be reduced "e" times (Moroz, 1967)

The arguments of the disputants appear to be based on present-day dissipation rates, which truly are low (Bates & Nicolet 1965). The reason for the low dissipation rates is that hydrogen in the oxygen-rich (21%) atmosphere is present mostly as water, which can only be released through photodissociation. Photodissociation is severely inhibited, because solar ultraviolet light, which causes dissociation, is largely filtered out by the ionosphere at altitudes of a few tens of kilometres. Water vapors cannot reach that altitude, because they condense and "freeze" as cloud in the troposphere.

In the past, however, conditions on Earth were radically different. Archean and early Proterozoic lithologies suggest that the atmosphere at that

time was denser, richer in the oxides of carbon, and most likely in methane and ammonium ion as well, but substantially oxygen-free (Holland 1971; Bergman 1971; Folinsby 1971; Ronov 1972; and others). Any considerable amount of oxygen could not appear before the mid-Proterozoic, a fact that is recorded by the onset of oxidation processes on the surface of the planet.

An atmosphere devoid of oxygen can retain elemental hydrogen. If the ancient atmosphere had been laden with dense oxides of carbon, a severe greenhouse effect along with high temperatures must have prevailed. Such an atmosphere would have contained a lot of water vapor (Sokolov 1971). Due to the heating from the greenhouse effect, atmospheric water vapor would not have been frozen at low altitudes. Photodissociation of water molecules was, therefore, much easier, and, even if some hydrogen had been supplied to the surface of the planet as water, the molecules of water vapor in the early history of the planet would have soon dissociated.

It thus appears that in the earlier stages of the Earth, when the silicate shell was forming, hydrogen emerged on the surface mainly in its elemental form. Later, as the outer geospheres were oxidized, the hydrogen was more and more released as water. However, in the oceanic rift zones, where metals occur close to the surface and the process of silication is at work, there have been recent discoveries of juvenile hydrogen. Data is lacking at this time on the prevalence of the phenomenon on a worldwide basis.

Vertical distribution of gas within the atmosphere is controlled by its molecular mass. We may make use of the simple formula of Bakulin and colleagues (1970) to describe the behavior of any particular gas.:

$$h = \frac{kT}{\mu\, m_H\, g}$$

where k = Boltzmann's constant, T = temperature Kelvin, μ = relative molecular mass of the gas; m_H = mass of the atom of hydrogen; g = free fall acceleration, and h = the scale of heights to be determined. Descending through the range of h for any given gas, the pressure and density of the gas both increase threefold.

In this formula, the density of hydrogen declines with altitude much more slowly than does the density of carbon dioxide. Therefore, the atmosphere must be considered as a two-tiered structure: a lower, denser tier with abundant, carbon-oxide-rich horizons, and an outer, rarified tier of hydrogen-rich composition. This atmospheric structure greatly facilitates the rise of hydrogen up to the critical level where, unimpeded by other gas molecules, it has sufficient freedom to dissipate into space.

Thus, hydrogen dissipation in the ancient Earth must have been vigorous. It is likely that in the present geological epoch, dissipation of hydrogen increases abruptly in times of magnetic-field reversals. At these times the outer dipole, which protects the ionosphere. is absent; and the level of cosmic and solar radiation are much more intense at lower atmospheric

levels.   Under these conditions the process of photodissociation of water vapor is invigorated.

Conditions on Venus, by contrast, now resemble those thought to have prevailed on Earth in the past.   The process of hydrogen dissipation on Venus, therefore, should at present be stronger than it is on Earth.   However, judging from its comparatively weak hydrogen corona, there is no hydrogen dissipation of any consequence on Venus now.   We must then conclude that the planet is presently at an interlude in its evolution when no degassing is occurring.   The planet may be passing through an expansion cycle, wherein there is no hydrogen released from its core.   However, degassing and dissipation of hydrogen should in the past have been a factor, and it should be expected in the future.   This is because, judging from its density, Venus *does* have a core.

As verification of the prognosis is beyond our capacity, we are tempted, instead, to look for evidence of unusual behavior on Venus in old chronicles.   Success would seem unlikely, because the historical memory of mankind is so short a span of time by comparison   with the time scale of planetary history.   Nevertheless there are in mythology surprisingly candid descriptions of Venus' unusual appearance.   Comparatives to the brilliance of the sun, to smoking, and having a tail are reported widely in ancient cultures.   The fragmentary and anecdotal evidence leads us to suggest that a thick corona of dissipating hydrogen could have been "blown off" by the solar wind and given the strange appearance of the planet.   It is an intriguing possibility that marked changes may have been observed on Venus in historical times.   If there is any truth to the myths, it may be observed that the only agency that have produced such effects is hydrogen, because of its capacity to escape and dissipate into space (Table 17).

CHAPTER XI

ON POSSIBLE WAYS TO VERIFY THE NEW HYPOTHESIS

Verification of the proposed concept may be possible in several ways. At the outset, experimental studies are required to obtain a wide range of temperatures and pressures in the Me - H system, for a variety of intermetallic compounds and alloys on the Fe - Mg - Si base, as well as a thorough examination of physico-chemical properties of hydrogen integration into various alloys and compounds. After the new experimental data have been accumulated, the hypothesis can be exposed to rigorous testing.

Future developments in astronautics will provide for ever-increasing returns of information from neighboring planets. This will help test our prognoses on their composition, interior structure, and particular physical and tectonic features. Of special interest are implications contrary to generally accepted doctrine.

Traditional notions attribute variations in the densities of terrestrial planets to the presence or absence of iron cores, whereas the magnetic activities of planets are assigned to convective processes in liquid cores. As a result, the traditional explanations allow for the generation of a magnetic field only on the planets that have a dense core, while precluding magnetic activity to planets with no cores. Given such an approach, there would be no reason to allow for a magnetic field on either the Moon or Mars now, or in the past.

According to our ideas, these planets must have had magnetic fields in their active stages, and corresponding evidence "registered" in the form of residual rock magnetization. Examination of lunar samples has, in fact, shown a stable residual magnetization, and, thus, suggests that the Moon must have had a field with an intensity around 100 A/m some 4 billion years ago. The field intensity declined exponentially; and 3.2 billion years ago was approximately 4 A/m (Taylor 1975).[1]

Thus, the existence of a strong magnetic field on the ancient Moon appears to be an argument in favor of our hypothesis and against traditional

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[1] A/m = amperes/meter

[2] *Residual magnetization had already been established, when researchers started to look for ways to allow for at least a small iron core that would permit a dynamo mechanism. However, they fail to explain why the Moon's dynamo (given a miniature core) would have been more efficient than that of the Earth. A strict limitation on the size of the core is imposed by the Moon's moment of inertia, which is close to that expected for a sphere of uniform density.*

notions.[2] Unfortunately, such a forecast, made post factum, would not stand as a test of the prognostication capacities and consistency of our ideas. We therefore, have to wait until data from Mars appear.

It may also be possible to check the process of magnetic separation of the elements responsible for the chemistry of the planets and fundamental to our hypothesis. The essence of this test would be to gauge the relative abundance of elements with disparate ionization potentials on various planets of the solar system. Some data are already available from the Soviet unmanned space stations operating on Venus. They helped in the comparison of abundances of argon and neon on our planet and its neighbors, and the results seem to match the predictions of magnetic separation (Chapter X, 1).

The U.S. "Vikings" have discovered that Martian soils have more iron than aluminum, in contrast with terrestrial soils, in which aluminum is dominant. The ionization potential of iron is slightly higher (7.90 V) than that of aluminum (5.98 V), and magnetic separation would result in a higher proportion of iron relative to aluminum at greater distance from the Sun (the Mars direction). Such verification, however, requires a comprehensive program of data accumulation on the elemental abundances of planets, a data bank that is always said to be insufficient. The author thinks otherwise and suggests that the data already available (Figures 1, 2 & 3) are enough to make the points required for our hypothesis on the basis of magnetic separation.

One way to approach the verification problem is to check a key postulation, instead of the local effects of our hypothesis. An unconfirmable key postulate would be taken as failure of the entire system. We could try to check the mean concentrations of the Earth's radioactive elements as anticipated on the basis of the magnetic separation mechanism. This examination is a matter of prime importance, because U, K, and Th concentrations in the body of the planet are an order of magnitude above those in chondrites. This should cause substantial expansion. Any planetary body with an invariable volume and such a level of radiogenic heat generation would otherwise be fully molten.

The Earth now is at its active stage, and its internal heat is consumed to sustain various phenomena, expansion being the leading one and the major consumer of energy. Therefore, on this planet there cannot be any correlation between heat flow at the surface and heat generation inside.

In the light of the traditional notions of the silicate composition of the bulk of the Earth's volume, to discount the existence of the high energy-consuming process of planetary expansion would require that there should be an approximate correspondence between the levels of radiogenic heat generation in the interior and the concomitant heat loss at the surface. In this way, the total heat budget of the planet can be sustained by the expenditure of uranium, thorium, and potassium at chondrite concentration levels.

If the Earth and Moon were born at the same distance from the Sun and under conditions consistent with magnetic separation, they must have started with equal mean compositions, including equal original concentrations of

radioactive elements. In contrast with the Earth, the Moon is at its passive stage, tectonically dead. As a result, its entire radiogenic heat budget is being expended to warm the body of the planet, whence its heat flow must reflect the magnitude of heat generation in its interior and the abundances of long-life isotopes. To this point the two viewpoints agree, although the traditional one assumes (or rather used to assume) chondrite abundances of radioactive elements on the Moon, whereas our point of view suggests concentrations an order of magnitude higher. This disagreement can be resolved through determination of the total heat flow emanating from the Moon's interior.

Based on chondrite concentrations, the inferred heat flow on the Moon is anticipated to be near 10 mW/m^2. Direct gauging has shown much higher values: Apollo-15, 31 mW/m^2; Apollo-17, 28 mW/m^2. This heat flow came as quite a surprise for the traditionalists, and cast doubt on the validity of the chondrite model. As for our model, the values seem, by contrast, insufficiently high, although not so low as to refute our model, which can tolerate highly disparate localized heat emissions on the Moon surface.

Thermal conductivity of intermetallic silicides is higher than that of silicates by an order of magnitude. Thus, heat-flux values at the surface of the Moon may be due to variations in the thickness of its silicate-oxide shell. Additionally, the continuity of the silicate shell can be disturbed by shock and explosion in the formation of the giant craters. In that case, breaches in the insulating silicate-oxide shell may result in tenfold growths of localized heat flows.

Thus, in contrast to the traditional point of view, which leads students of the subject to treat their observations of heat flow on the Moon as abnormally high and look for possible explanations of this abnormality, our concept suggests there should be some hope that future studies will find still higher values, up to n·100 mW/m^2. This prediction can be used to test our hypothesis for its power of prognostication. No other basis for such elevated readings has been made. The best choice for the potential discovery of the predicted "super-anomalous" heat flows on the Moon is the Tycho Crater. The reasons for this choice follow.

It is believed that the Earth may also be capable of developing a new thermal phenomenon, which will tentatively be termed a "thermal paradox of rift zones." It falls totally beyond the framework of traditional doctrine,.

In light of our concept, the entire endogenic energetics of the Earth are viewed in a radically different way from the traditionally accepted one. Unfortunately, these new energetics can be discussed only qualitatively. We know nothing yet of the values of enthalpies of chemical reactions in the inner geospheres of the planet, nor of the thermal capacities of the phases involved or phase transition entropies, etc. With time, as these thermodynamic parameters become known, quantitative assessments should become possible. Nevertheless, even now there are some phenomena (to

come from our theories alone) which have not yet been discovered and may serve to test the ability of our ideas for prognostication.

Already mentioned was the cyclic pattern of decomposition of the hydridic core, when internal planetary zones are from time to time either heated (whence hydrogen degases from the core), or cooled (due to the heat-consuming decompaction of the core). According to our model, the substance of the core, when decompacted, would in part contribute to expand the lower mantle, and in part funnel upward into the planetary rifting zones (Figure 47).

The magnitude of volume incrementation that occurs with decompaction and the pressures involved are known, judging from the sudden increase in densities at the core-mantle interface. It is, therefore, possible to estimate, from the formula $DQ = pDV$, the amount of thermal energy required for this process. It proves to be exceptionally large. For example, if the outer sphere of the core, prior to decompaction, had been heated to temperatures of thousands of degrees, decompaction would have absorbed the entire thermal resource, and the mass would be chilled, probably to a temperature less than 0°C! The mass would still remain plastic, due to residual dissolved hydrogen. Under super-high pressures, as our experiments have shown, super-plasticity may be expected. In such a "liquified" state the mass would barely be heated by internal friction as it moved towards the surface of the planet. This effect would be reinforced during upwelling, because the mass must undergo almost twofold decompaction. It follows that deep-seated intermetallic diapirs coming up the rift zones should be cold.[3]

In the majority of cases, intermetallic silicides would at some level at the surface contact vadose waters or the water of the hydrosphere. As earlier discussed, this would generate a silicate-oxide "rind" and heating. Hence, high heat flows should characterize rift valleys. At the same time, this local heating should be declining very fast, being not fed by heat from depth but, instead, nullified by rapid cooling from its interior. The "rind" would move away from the axis of the ridge, thus inhibiting further oxidation. This scenario of anomalously rapid cooling of newly-formed oceanic crust appears to be supported by observation (Suetnova 1987).

Sites occur where contact between deep oxygen-free mass and water is inhibited. One such group of sites are the rift-type troughs of the Baikal system. These occur in a permafrost belt, where a thick layer of permafrost blocks penetration of meteoric waters into the structures. Of course, there should be some vadose waters beneath the permafrost, but without an inflow

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[3] *The suboceanic mantle at depths of a few hundreds of kilometres is thought to be hot, as seismic tomography suggests. We interpret low velocities of the mantle beneath oceans as a consequence of the fact that it is represented not by silicates (as it is beneath continents at the same depth) but by intermetallic silicides, with lower-velocity seismic waves (Figure 49).*

from above, they are quickly exhausted, and heat generation under these conditions should be much suppressed. We believe that such zones may be hosts to a "thermal paradox." Heat flow in the rift valley should be below background values typical of the region.

A possible illustration of this situation is contained in data on the Muya-Konda trough (Lysak 1988). The trough is over 260 km long, from 10 to 45 km wide, and contains up to 1.5-2 km of unconsolidated sediments. Its layer of permafrost may be as thick as 200-300 m in sediments. Oon the surrounding ridges it is even thicker. In vast areas of undisturbed permafrost, the heat flow is below 30 mW/m^2 (varying between 19 and 29 mW/m^2), which is much below the background values of ancient shields and platforms (45 - 65 mW/m^2). This structure is seismically very active and contains zones of high electric conductivity in the crust, underlain by a diapir of anomalous mantle.

To settle conclusively whether or not such a "thermal paradox" does exist in nature, riftogenic troughs, which have received only minor research, should receive continued study. Where a layer of permafrost has sufficient thickness to obstruct inflow of meteoric waters, its presence precludes convection. That restricts heat loss to the small conducted component. The few necessary gaugings required to test this paradox should be made to resolve it. It is to be hoped that a radical reformulation of the problems that affect the database available for geological theorization may attract the attention of authorities, so that we may not wait long for the needed information. The suggested gaugings as means of verification are indirect and unable to provide direct data validation of the concept.

A direct solution would be intersection by drilling of metallic substance in the mantle beneath the silicate-oxide shell. For this purpose a combined geological-geophysical study on the Earth of rift valleys in mid-oceanic ridges may be invaluable, as the ridges are believed to host diapiric C-layer intermetallic compounds in their subsurface horizons. The attempt should be made to identify zones where intermetals are closest to the surface. Progress in drilling technology then makesverification both possible and timely.

Whereas this test can be accomplished either on the Earth or the Moon. The Moon offers some distinct advantages, inasmuch as it is a sphere of intermetallic, oxygen-free, compounds covered at the surface by a silicate shell, with an average thickness hardly more than 60 km (Fgure 72). Its formation was assisted by oxygen expulsion in the process of hydrogen purging of the Moon's interior. As the hydrogen flux must have varied widely from place to place, so should the thickness of the silicate shell. It has been shown above that it may increase to 90 km within the mascons, but of more interest is the minimal thickness. We may draw an arbitrary comparison between the Moon with the Earth. On the latter we take the thickness of the silicate shell as the depth to the top of conductive mantle. In some regions this may be reduced to one-half or one-third. This is

exclusive of spreading centers and oceans, under which the metallic mantle is shallower still. Given similar variations on the Moon, the thickness of its silicate shell may be reduced locally to 20-25 km.

Experimental and theoretical studies of explosive craters ["Vzryvnye...", 1968] have shown that immediately after an eruption, the depth of the explosive funnel may be as much as one-third to one-fourth of subsequent relict crater diameter. Much of this is immediately back-filled with fallback debris, which brings clasts of the deepest rocks from the excavation to the surface.

The shock and explosion features on the Moon include craters radially centered within systems of light-colored rays. These craters may be a few tens of kilometres in diameter (86 km in the Tycho Crater; 90 km in the Copernicus Crater; 46 km in the Aristarch Crater, etc.). Consequently, the eruptive funnel may be as much as 20-25 km deep. For this reason we think that on the lunar surface the debris of major explosive craters may contain unoxidized metallic alloys, intermetallic silicides extracted from under the silicate shell of the planet. The most attractive in this respect is the Tycho Crater, which has the brightest of the radial systems and rays that can be traced in several directions for thousands of kilometres (Figure 73). As the nature of these rays is unclear today, we venture the prediction that their high albedos are the reflective properties of unoxidized metals.[4]

Further indirect evidence favoring this hypothesis is the unusually high reflectivity of radar signals in the vicinity of the Tycho Crater (Kaula 1971). Metals are known as the best reflectors of radar signals. Additionally, there is a significant correlation between "hot spots" on the Moon and radial craters (Shorthill & Saari 1965), a correlation that may result from a "breach" in the silicate thermal insulation. The radial-rayed craters may effectively be "vents" for the internal energy of the Moon, and their heat flow may be dramatically high.

By reason of the Moon being subject to constant meteorite bombardment, the material expelled from its interior must be mixed with clasts from its silicate-oxide shell. Oxygen should, therefore, be redistributed between silicates and silicides. In chemical reactions involving unoxidized (native) metals, those abundant elements most likely to be left unaltered are elements with low affinities for oxygen, such as iron and nickel. At this writing, native iron has been found to be widespread in trace amounts on the Moon. Although its presence may indicate incomplete oxidation of the outer lunar surface rather than the expulsion of clasts from the interior, the occurrence conforms to our hypothesis and to expectations based on the experimentally determined low values of oxygen fugacity, which lead to the crystallization of native iron (Motoaki 1976).[5]

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[4] *Ed. note: The high albedo of Tycho, other rayed craters, and their associated thermal anomalies are considered merely effects of "roughness and thin regolith." by investigators for the Shuttle Imaging Radar experiments and the CCRS ERS-1 radar team (pers. comm. P.D. Lowman, Jr. , Goddard Space Center).*

[5] *Ed. note: Investigators for the Apollo samples regard the native iron to "result from the absence of water in the parental (basaltic) magma (pers comm. P.D. Lowman, Jr.).*

In the Oeeanus Procellarum light-colored "terrae" are flooded by dark basalts. Where these are observed with radial crater systems they may be explained as eruptions of anorthosites. So, it would be better to test our forecasts in the Tycho Crater and its radiating rays, which are much brighter than even the lightest colored terrae. We would hope to find unoxidized Mg silicides, Fe silicides, and other similar compounds there, as well as native metals. We hope that future studies will pay due attention to the Tycho Crater, one of the brightest features on the near side of the Moon.

Figure 73 is the familiar view of the near side of the Moon and Tycho Crater.

CHAPTER XII

ENERGY RESOURCES ON EARTH AND ITS ECOLOGY IN THE LIGHT OF THE NEW MODEL

The present-day situation in the evolution of the earthlings' civilization is more and more that of a gridlock. On the one hand, further progress and prosperity increasingly requires energy while, on the other, this may lead to such a level of environmental pollution that prosperity will hardly be imaginable.

Oil and gas reserves appear tangibly finite, thus focusing the spotlight on the issue of what is less hazardous, coal or the "peaceful atom." Burning coal discharges huge amounts of carbon dioxide into the atmosphere, which creates a growing concern that, due to the greenhouse effect, the climate of this planet may change radically in the near future. Besides, even the small component of sulfur in coals utilized in the furnaces of thermal power stations is enough for acid rain that inflicts serious damage to the environment.

In this connection, more and more voices are raised in favor of the environmentally clean nuclear stations, which, in the wake of the Chernobyl disaster, stirs nothing but awe in some of us. Admittedly, new-generation reactors may be safer, armed conflicts may be eliminated, and an ultimate solution to the problem of nuclear waste disposal may be found. But life would, nevertheless, be like resting on a powder keg, which by operational fault, ill-conceived design, or deadly coincidence, could explode into the global atmosphere. It is unreasonable, even reprehensible, that progress should be paid for at a price of future life nagged by the unremitting anguish of mortal danger. No mind could retain sanity for long under such conditions.

So, the existing situation seems to offer a poor choice between slow suffocation as the burning coal consumes the air, or a life (with luck) in constant fear.

In the meantime, the new model of the Earth opens a new and exciting vista for planetary energy resources. If you remember, geophysical data suggest that every zone of modern rifting sits on a diapir of "anomalous mantle" which, in our view, must be made up of oxygen-free compounds and alloys. Seismic velocities and densities typical of the diapiric outliers of the anomalous mantle seem to match those of the iron - magnesium - silicon alloy that is invoked by the new model.

Seismic data suggest that in the Baikal rift zone, diapirs of the anomalous mantle may rise to 40-50 km beneath the surface. Given possible saturation with hydrogen, albeit at low levels, the diapir interior may be expected to be highly plastic, and thus capable of penetrating as discrete tongues or domes into and through tectonically relaxed zones all the way up to shallow horizons in the crust.

Of particular interest in this respect is evidence of anomalously high electrical conductivity in rift structures at depths of 10, 15, 20 km, or locally to depths as shallow as of 7-8 km. Explanations invoked routinely to account for these phenomena (sulfides, graphitization, mineralized water, or high temperatures) all introduce contradictions. The proposed model, on the other hand, reconciles the high electric conductivity at these depths with crustal penetration by tongues of deep-seated oxygen-free silicides.

Deep electromagnetic probing suggests that electrical conductivity in rifts is at semiconductor levels, that is to say, several orders of magnitudes lower than conductance in metals and higher by several orders of magnitude than the electrical conductivity of dielectrics, such as rock silicates. This degree of conductivity fits well in our model, because Mg and Fe silicides and native silicon are all semiconductors.

Scholarly efforts spearheaded towards the Baikal rift zone and adjacent territories have resulted in a map of He isotope topology (Polyak 1988), which shows $^3He/^4He$ ratios in the Tunka trough[1] up to 10^{-5}, suggestive of structures totally devoid of a continental crust. At our request, the structure was subjected to deep electromagnetic probing. In its midsection the trough was found to have a zone of high electrical conductivity at a depth of 6-8 km.

Thus, our hypothesis suggests that the interiors of rift zones accommodate oxygen-free intermetallic silicides, which have ascended to levels that are accessible to state-of-art drilling. This forecast can pay off handsomely if verified in drilling. Apart from the scientific results, there may be immense practical value, a radically new source of energy having been discovered.

By interaction with water, silicon and magnesium, the predominant deep-seated oxygen-free materials, are oxidized with the release of large amounts of heat and hydrogen. If it is possible to pump in water in the zones where the metals reside unoxidized, we can obtain energy in the form of "hot hydrogen." By burning hydrogen, we would get much energy and the same amount of water as we pumped in for metal oxidation. The thermal effect of this source of energy would be comparable, per unit of mass, to the calorific value of the best coal grades, while the amount of oxygen thus consumed would be much less.

It is to be noted also that the new source of energy holds the promise of environmental cleanliness. Hydrogen is the fuel of the future, producing

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[1] *The Tunka rift trough is situated in the southwestern part of the Baikal rift zone. It is perfectly outlined by geomorphology through a length of 150 km (longitude) and a width (at the middle) of 35 km (latitude).*

only water when it is burned. Specialists argue that transmission of energy in the form of hydrogen (by pipelines) cuts the losses almost by an order of magnitude, by comparison with losses incurred in the transmission of electricity over high-voltage lines. Hydrogen shows promise as a fuel in internal combustion engines and turbines; and these uses do not exhaust the list.

However, to date it has been equally clear that to obtain this ideal clean fuel, we have been compelled to burn a "foul" energy in quantities greater than what we would recover when we burned the produced hydrogen. This is because of unavoidable losses in the technological chain.

Tapping intermetallic lodes for hydrogen may produce it with no net energy input. This procedure could be a wonderful alternative to the seemingly dead-end contradiction between the need for the ongoing satisfaction of the ever growing demands and the necessity of keeping the environment clean.

Based on the apparent size of the conductive bodies of oxygen-free alloys and their height of penetration into the crust, this source of energy may prove inexhaustible for man's requirements. We simply need to know whether we have any chance here to succeed – the sooner the better, before traditional means of energy production have brought the planet to the brink of ecological catastrophe. We should recognize that, should the prediction be correct, it may still take a great deal of time to overcome technical complexities that always beset both exploration for newly conceived sources and the technology involved in their production and utilization.

We suggest conducting superdeep drilling in the Tunka trough (or another like one). If successful and the prognosis proves correct, this venture may ultimately lead to ecologically clean energy production, providing a safe alternative to nuclear reactors. Even if the prognosis does not prove to be economical, the investment should be recouped in other ways. Generation of rifts is the controlling factor on Earth's surface today. Elongate zones invariably anomalously electrically conductive, these zones are seismically active and in some places densely populated. An unequivocal definition of the material makeup of the highly conductive zones is key to understanding the planet and its geodynamics. Finally, quite simply, we ought to know how our planet is constructed. We can only hope that our concern is shared by many others, who may be able to help implement the project.[2]. Clearly, this could be a place for international cooperation.

In addition, as we would be penetrating deeper into the interior of the rift zone, cutting through young sediments and into the ancient crystalline basement. We may encounter jets of hydrogen emanating from deep in

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[2] *The studies carried out in this region (including a few field seasons by the author) helped to compile a comprehensive program that includes all technical aspects of appropriate exploration (mostly geophysical) to precede drilling, along with program details and costs, including the total cost estimate for drilling of one will 8 km deep.*

the inner spheres of the Earth. Such jets are typical of rift zones and may in many places approach the surface. Hydrogen is sufficiently chemically active to seep upwards through the sequence of rocks and sediments that contain free oxygen, and drilling may facilitate its release.

Finally, it is noteworthy that the new model allows for exceptional rates of hydrogen degassing and adds significantly to the planet's potential in traditional fuels such as oil and gas. It is notable that the flow of juvenile hydrogen in the mantle, crust, or sedimentary cover should react with carbon (in graphite form or as organic debris) and emitting a broad spectrum of derivative hydrocarbons. This potential may justify questioning the thesis of ultimately exhaustible oil and gas deposits. We would claim that petroleum is even now being replenished as the hydrogen degassing continues. It is hard to judge the probable rates of replenishment, however, for a practical yield. In any case, if replenishment of the extracted fraction of long-abandoned deposits can be proved locally to be occurring, it would be a global phenomenon that should be taken into account in considering conservation. Depleting oil and gas fields may yet see better times in future.

EPILOGUE

The hypothesis that the Earth and kindred planets were primordially hydridic appears satisfying even when first considered. Its fundamental reliance on specific cosmochemical regularities, and its consistency with present knowledge of the physics of the core and mantle of the planet, provide an easy resolution to the enigma of geomagnetism. What is even more important, it relies on a single primary process, hydrogen degassing, which allows an integrated explanation for the entire spectrum of global geological phenomena. These include ocean formation and geosynclinal processes, orogeny, magmatism, and mountain building. The new geology enables understanding of the intrinsic causes and energetics that have lead to the evolution of the geodynamics of geological history from the earliest stages. It is particularly noteworthy that this hypothesis takes into account the entire volume of the globe, from the inner core to the outer crust. In the process it opens exciting opportunities for applied science.

Many deductions made in the foregoing discourse are purely intuitive. The author is at pains to acknowledge that they, indeed, may in future require incisive changes. The purpose all along, however, has been to show that the proposed hypothesis provides the opportunity for rigorous rationales that cover an exceedingly broad spectrum of geological and planetary regularities, and that comparable rigor is quite impossible with any other presently conceived hypothesis.

Many phenomena have been predicted by the author as logical inferences from the new model of the Earth that have now been established as reality. This was the path followed in deciphering the enigmas of geosynclinal evolution from its early to its later cycles. The concept of two-stage uplifting of fold belts was developed in this manner. Longitudinal wave velocities within the Moon was another. The effectiveness of these explanations to complex enigmas offers solid evidence in support of the hypothesis.

Our approach, from the general to the specific, is unusual in geology. However, as Albert Einstein argued, "...the supreme duty of physicists is a search for those general elementary laws from which through pure deduction one may obtain the picture of the world" (Einstein 1965). If we want geology to achieve the status of an academic discipline, it is our conviction that this approach is the appropriate one. The hypothesis set forth in this book is an attempt to move precisely in that direction.

We have intentionally avoided detailed elaborations of specific problems, as this approach would only add to opposition over contentious detail and pose a real danger that the major concepts would be submerged by argumentation with experts on particulars. We have aimed to provide a general, comprehensive picture that would interest the broadest possible circle of researchers and spearhead discussion on the validity of the idea in principle.

In ending, we would like to go back to the starting point of our discussion, and again to emphasize that the hypothesis of the oxygen-based composition of the Earth has never been proved. Unfortunately, this fact is no longer remembered and, over time, has become entrenched as dogma. It is generally believed now that the burden of proof, logically, should be borne by any newly proposed hypothesis. Having accepted this dogma, theoreticians in geology have proven incapable of controlling the process of cognition. Ill-equiped to provide prognoses, they are hard put to accept any major discovery. We have, remarkably, come to live with this obstinacy. It is a bad posture, one that masks fundamental error at the very base of our knowledge of the Earth.

Earth scientists have not even come close to having a comprehensive, unifying, basic theory, or even a correct premise at the base of their science. They have shut themselves off, each tending to develop independently, often inventing his own specialized hypotheses or models uncoordinated with other researchers. All this has led to a conviction that geology is too complicated, and that geologists are comfortably ready to swallow any contradiction of their theories, and to do so without indigestion! Even worse, there is widespread belief in a frequently-heard maxim that declares that any attempt to create a unified theory of the Earth should be discouraged, because Earth phenomena are so complex that the effort to find order among them makes no sense now and never will in future.

We cannot accept this prescription, and, rather, incline toward Isaac Newton's view that "nature is simple, and does not wallow in superfluous causes." The history of science has proved the truth of this statement repeatedly. We may hope that it will do so once again and that our hope will be fulfilled with the establishment in future of a general theory of the Earth.

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